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A quarterly paper devoted to the sugar interests of Hawaii and issued by the Experiment Station for circulation among the Plantations of the Hawaiian Sugar Planters' Association.

In This Issue:

Weather and Crop Relationships at the Honokaa Sugar Company:

Our previous weather studies were based on typical irrigated and unirrigated plantations. Herein we present the case of Honokaa Sugar Company, which belongs to neither of the two groups mentioned above and which has many peculiar complex problems of its own. But here also we find that the general weather influences are of the same nature as found elsewhere and that we are in a position to measure the magnitude of these influences. This study further confirms our belief that no matter where we are situated or what our particular problems are, we have to reckon with weather as one of the major factors in crop production.

Response of Cane Plants to Soil Sterilization:

The effect of soil sterilization by steam, formaldehyde and chloropicrin is reported. A great increase in top and root growth of cane is shown in the sterilized over the unsterilized pots. The results of the examination of roots and soil for Pythium or nematode infestation are reported. A summary of the work of other investigators on the subject of soil sterilization is given, in which explanations are presented for the differences observed in plant growth in sterilized and unsterilized soils.

Pedigrees of Some of the New Seedlings:

The pedigrees for some of the more interesting combinations made during the 1931-1932 crossing season are listed. The crosses which are considered suited to special agricultural conditions, as mauka unirrigated, makai irrigated, etc., are grouped under these headings. The crosses with the newly imported *robustum,* Indian, and Australian blood lines show the use of a wide range of the commercial Hawaiian varieties.

Plant Wilt and Its Relation to the Rate of Water Supply and Water Demand:

This paper is a non-technical discussion of the factors which bring about the condition of wilt in plants. It is argued that such conditions are brought about by

a demand for water by the leaves at a rate greater than the potential rate of supply by the roots. A careful distinction is made between "temporary wilt" and "permanent wilt."

A Summary of Recent Irrigation Studies and Some Suggestions for Future Investigations:

The general conclusions from three years' intensive study of plant and water relations in Hawaii are briefly summarized. In general, local findings are in accord with the results of extensive studies elsewhere.

Future work may well be founded upon these conceptions. Studies of the role of soil moisture in cane ripening and of the attributes of drought resistant varieties are suggested as worthy fields of investigation.

Hilo Forest Reserve:

A very clear and illuminating account of the work accomplished in the Hilo Forest Reserve during the past ten years by Forestry Unit No. 3 in cooperation with the Territorial Division of Forestry is given.

The Recovery of Potash from Molasses:

An account is given of how one plantation is burning molasses to recover the potash. The molasses ash is placed in the irrigation water by means of a device designed for the purpose.

Plantation Interval Tests:

A presentation and discussion of results from typical irrigation interval tests on the plantations of the Pioneer Mill Company, Koloa Sugar Company, and Lihue Plantation Company are contained in this issue.

The trends indicated by these experiments may prove valuable aids in our interpretation of the response of cane growth to soil moisture, and in the practical manipulation of our field irrigations.

A Summary of Recent Irrigation Studies and Some Suggestions as to Future Investigations

By H. A. Wadsworth

In general, irrigation investigations at the Experiment Station of the H. S. P. A. have, for the past three years, been directed towards verifying, under local conditions, certain basic conceptions of soil moisture and plant and water relations, which have been expounded elsewhere.

With certain minor exceptions, primarily of academic interest, these basic conceptions have been found applicable to local conditions. Future work in irrigation studies may be based upon a foundation which is theoretically sound in view of the exhaustive studies made eslewhere and the demonstrated concordance of local results.

These conceptions may be summarized as follows:

(1) All soils exhibit a critical soil moisture content which cannot be exceeded when free drainage is provided. Naturally, this soil-moisture percentage varies with the kind of soil, being low for gravelly soils and high for finely divided colloidal soils. This critical constant may be determined by simple laboratory means. This procedure permits the location of areas requiring expensive and uneconomic "dry spotting."

(2) All plants growing in a given soil give evidence of soil-moisture shortage at approximately the same soil-moisture content. With sugar cane this evidence of soil-moisture shortage occurs in the form of growth cessation and not as evidently flaccid leaf tissue. This principle permits the determination of the lower limit of available soil-moisture by means of rapidly growing plants in small containers.

(3) Growth of sugar cane is equally rapid between the critical soil-moisture contents mentioned above. Consequently, it is neither possible nor desirable to maintain a predetermined moisture content such as the so-called "optimum moisture content." Several field observations have demonstrated the soundness of this conception, which the detailed tank work has demonstrated and which theory demands. At Ewa growth measurements in the field have indicated a period before the cessation of growth in complete concordance with the desirable intervals as determined by Alexander. At Waimanalo similar methods have demonstrated adequate soil-moisture penetration at critical points along the long lines in the experiment recently reported.

Naturally, this conception gives a new point of view which is of value in interpreting the results of the classical "interval tests." It is evident that:

(1) Irrigation at more frequent intervals than that indicated by the criterion of growth cessation adds nothing to the rate of growth and is wasteful of water.

(2) Irrigation at intervals longer than that indicated by the criterion of growth cessation is wasteful of growing time. Moreover, a permanent handicap may be encountered if the plants are allowed to suffer at critical periods of growth. This aspect deserves further study.

Suggested Investigations

In view of the uniformity of local results with those secured elsewhere, future work in irrigation research may well center about the relation of soil-moisture to sugar formation.

Tradition holds that irrigation should be withheld for 60 to 90 days prior to the proposed date of harvest for maximum sugar yields. Recent evidence on this point is contradictory and inconclusive. The relation between available plant nutrients, particularly nitrogen, during ripening, available soil-moisture and total sugar is not well understood. On some plantations irrigation is "tapered off," that is, the long period of drying off is broken into shorter periods of increasing length. The reason for this arbitrary practice is not clear.

The comprehensive attack of this problem requires growing of cane plants under such conditions that unquestioned soil-moisture control is possible. The tanks at Waipio provide such control and are available. Although well adapted to qualitative work, such as studies of changes in rates of growth, they are strictly limited in their use in studies of sugar formation.

It seems well established that sucrose once synthesized and stored in a cane is subject to reversion to simple hexoses through the action of the enzyme invertase. If the recoverable sugar in a cane at harvest is a function of the relative activity of invertase, other things being equal, it seems logical to suppose that cane grown in tanks might give entirely different figures for quality ratios than cane of similar age in the environment of a completely closed-in field, although adjacent tanks should be mutually comparable.

We have some evidence that the temperature inside a closed-in cane field is significantly lower than the temperature in the shade at the tanks. Little is known of the effect of temperature upon the activity of invertase. The fact remains, however, that in a crop grown for two summers and one winter the quality ratio secured from the tanks was significantly poorer than in the field control. In the next crop, covering one summer and two winters, the quality ratios from the tanks were better than the field control.

The leads seem worthy of further study as contributing to the general knowledge of cane ripening.

Without detail as to procedure it is suggested that the problem of the effect of soil-moisture, available plant nutrients and temperature upon cane ripening be actively studied in the tank farm and as much adjacent area as is available. One great advantage lies in the fact that little or no new equipment would be required. All costly apparatus is on hand. If intelligently planned and actively prosecuted, such a project would contribute materially to our knowledge of cane ripening.

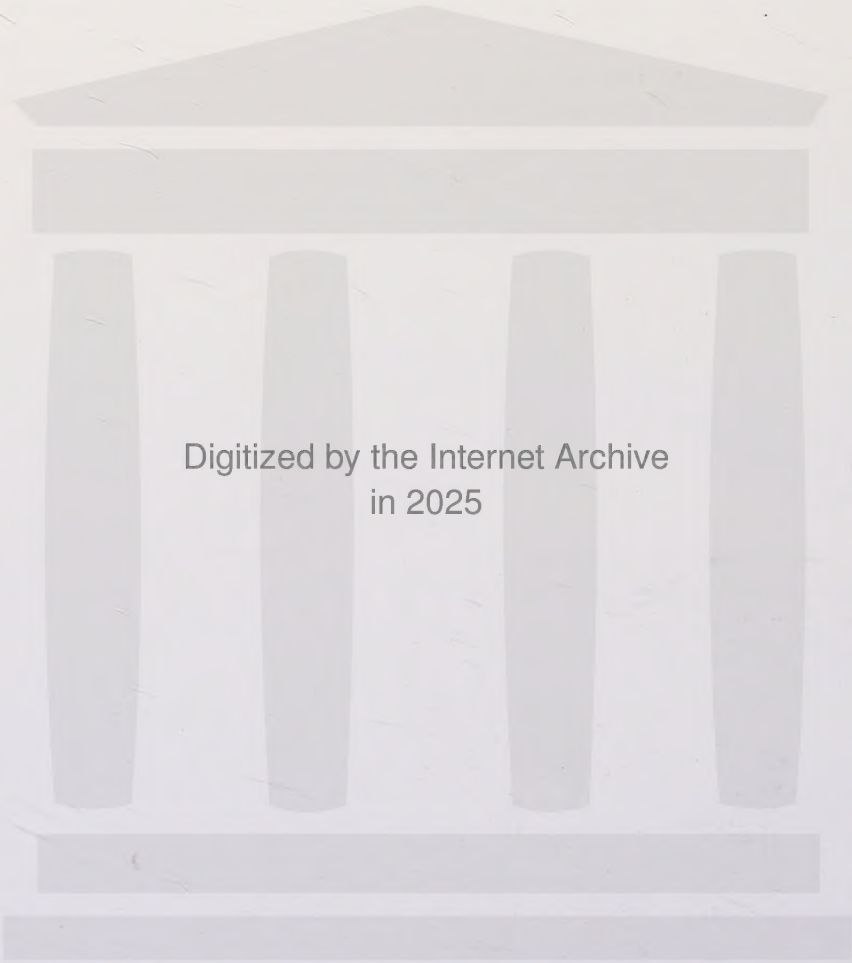
Considerable work has been done in an effort to determine the significance of so-called drought resistance in some cane varieties. Results from one crop indi-

cate that recognized drought resistant varieties possess deep, well-ramified root systems, which provide extensive soil-moisture reservoirs and leaf systems of such character that water expenditure by transpiration is at a slow rate. Study of this problem throughout the ratoon crop is essential, however, for unquestioned conclusions.

This work is fundamental in character. The principal costs involved are in labor, mainly "off-season" labor.

It is felt that these two major research problems will form a sufficiently heavy load for the personnel of the irrigation staff as now organized. Other enterprises, such as a study of the surface forces in local soils and the physical properties of local soils are too academic to demand attention during the current emergency. They form attractive fields of research, however, and may well be resumed at a later date.

It should be remembered that the prosecution of investigational projects forms only one part of the work of the available personnel. Plantation advice with respect to methods of irrigation and water measuring is time consuming and of compelling importance.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Manufacture and Distribution of Potash From Molasses

By H. S. Harkness
Chemist, Hawaiian Sugar Company

The burning of molasses for potash recovery is not new. During 1915, several Hawaiian plantations burned their molasses for the potash and at that time it was a very profitable undertaking as potash was then worth about 20 cents per pound. The present cost of potash is around 4 cents per pound, but since there is practically no sale for molasses the Hawaiian Sugar Company determined to see if they could not profitably burn their final molasses and recover the potash in the ash.

Production

Three molasses burning furnaces were erected in January, 1932. The first furnaces proved unsatisfactory, chiefly because of the method of dehydrating the molasses. The furnaces were then rebuilt and revolving drums with water-cooled shafts were installed in each unit. The function of the drum is to preheat the molasses and remove as much water as possible before the molasses reaches the fire.

We are now able to burn from 18 to 20 tons of molasses and produce from 3,000 to 3,400 pounds of ash daily. Eight men are required to operate the furnace: two for cooling and bagging the ash and three men per shift to tend the furnaces, one man being in charge of each unit. Fig. 1 shows in some detail

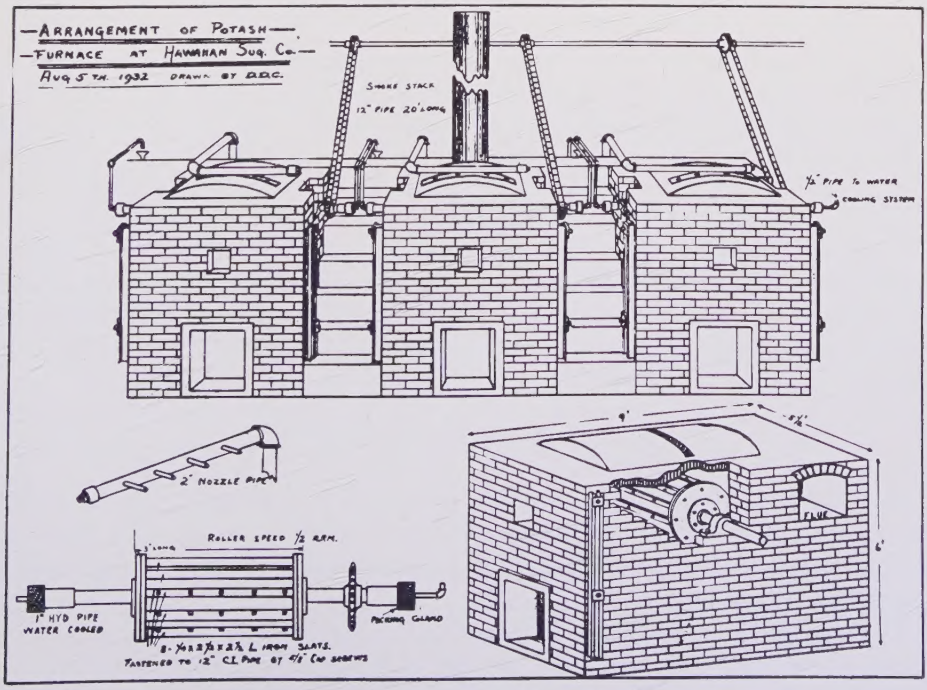


Fig. 1. Showing arrangement of molasses burning furnaces.

Fig. 2. Showing molasses ash drums in operation.

the general arrangement of the furnaces. Those desiring a full description of them and their operation are referred to a report, "Potash Recovery From Molasses," by the writer, and published in *Reports of the Association of Hawaiian Sugar Technologists for 1932.*

Recovery

For every ton of molasses burned there is produced about 170 pounds of ash. The ash is from 33 to 37 per cent K_2O or about 56.1 pounds of potash for each ton of molasses burned or a recovery of about 2.5 to 3.0 per cent potash on molasses.

Field Application

After producing the ash we then had the problem of proper field distribution. Spreading by hand would be too expensive as it would mean an extra round by the fertilizer gang. Also the ash is very light and dusty and it would probably be a very disagreeable job.

Various methods of distributing the ash in the irrigation water were tried. Drums or barrels, such as we use for the distribution of nitrate of soda, were tried, with no success. The insoluble part of the ash would settle and pack in a

Fig. 3. Showing false bottom in one of the drums.

very firm layer on the bottom of the drum and would not flow. False bottoms were then made and installed in the drums at an abrupt angle so that all movement was toward the outlet cock. We also installed 1½-inch outlet cocks to obviate clogging. Screens of about the same mesh as window screen were used on top of the drums to remove pieces of clinker or carbon so that no large pieces could go through to block the outlet. This arrangement works very well and requires one man for its operation. The drums are used in sets of three: two large drums are used as stock tanks and are emptied alternately and the small drum is used as a regulating tank so that the same amount of ash is constantly flowing in the water. The drums can be used over any ditch in the field and are best suited for the supply of 4 to 6 irrigators, as their capacity is limited. Fig. 2 shows the drum arrangement in operation, and Fig. 3 a view of the false bottom in one of the drums.

Perhaps the best apparatus developed for the distribution of the ash in irrigation water consists of a hopper with a variable opening in the bottom through which a corrugated plunger, made of heavy wire, operates from an eccentric shaft which is driven by a waterwheel attached to the hopper. The machine is constructed almost entirely of wood and is light enough so that two or three men can easily carry it from place to place. In operation, the machine is set over any

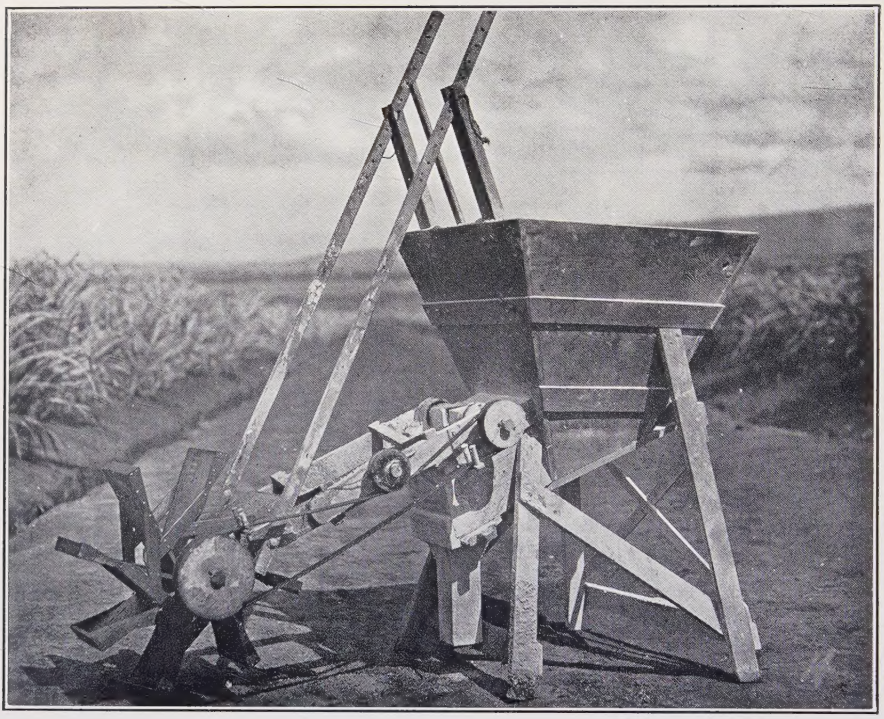


Fig. 4. Showing ash distributing machine.

main or level ditch supplying the acreage over which it is desired to distribute the ash, and the waterwheel lowered into the water.

After the machine is in place and the hopper filled with ash its operation is practically automatic. The corrugated plunger keeps a stream of ash constantly flowing into the water and as long as the ash is dry there is little to do except to keep the hopper full and remove occasional clinkers or lumps which obstruct the flow. Damp ash has a tendency to stick and requires frequent poking with a stick. The machine is very elastic with respect to capacity and can be used to supply either small or large gangs. We have found little difficulty in feeding up to 1000 pounds per hour with one man and he has time to weigh the ash.

Production Costs

It is rather a difficult matter to work out a fair cost figure on ash production for this first period of operating (to July 1, 1932) as there must be included not only ordinary operating and upkeep costs but also the rebuilding costs, making, however, no charge for the molasses burned. We therefore propose to present two sets of cost figures:

Case 1. Showing actual figures to July 1, 1932, which include all rebuilding, upkeep and operating expenses.

Case 2. Showing calculated costs over a six-month period, when burning

an average of 20 tons of molasses per day, and including only ordinary upkeep and operating expenses.

Going back to Case 1, we have the following figures:

Labor	$1,855.75
Supplies	529.18
Total expense	$2,384.93
Molasses burned	1,266 tons
Ash produced	215,220 pounds
Potash in ash at 33 per cent	71,022 pounds
Value of potash at 4.106 cents per pound	$2,916.16
Cost of potash (labor and supplies)	2,384.93
Saving	$ 531.23

This amounts to 0.748 cents per pound of potash and gives a value to the molasses of 42 cents per ton. Using 120 pounds of potash per acre it means a saving of 89.76 cents per acre or $897.60 per 1000 acres.

Case 2:

Labor (156 days at $8.94)	$1,394.64
Upkeep	200.00
Total expense	$1,594.64
Molasses burned at 20 tons per day	3,120 tons
Ash produced at 170 pounds per ton molasses	530,400 pounds
Potash in ash at 33 per cent	175,032 pounds
Value of potash at 4.106 cents per pound	$7,186.81
Cost of potash (labor, etc.)	1,594.64
Saving	$5,592.17

Per pound of potash this amounts to 3.1949 cents and gives to the molasses a value of $1.79 per ton. Using 120 pounds of potash per acre it means a saving of $3.83 or $3830.00 per 1000 acres.

From the above figures it is self-evident that whenever we are able to sell our molasses for more than $1.79 per ton it will not pay to burn it for the potash.

Field Application Costs

We are not at the present time able to give positive figures on the cost of applying molasses ash as fertilizer and the figures which will be given should be regarded as simply an indication of what to expect.

Ordinarily we use a mixed fertilizer containing definite proportions of nitrogen, phosphoric acid and potash, which is known as the HS2 formula. It must neces-

Fig. 5. Ash distributing machine in operation.

sarily be spread by hand as we are unable to use a fertilizer gun or similar apparatus on account of its physical condition. However, when applying molasses ash we use a mixture called HS3, which contains about double the percentage of nitrogen and phosphoric acid as HS2, but no potash. Where we used 5 bags per acre of HS2 we now use only 2.75 bags of the more concentrated HS3.

The *ukupau* for HS2 was 10 bags per man and when the HS3 mixture was started we still held the men to the old *ukupau*. This was made possible by the fact that the HS3 mixture is not lumpy and is fairly free running and we are able to use a fertilizer gun (patterned after the McBryde fertilizer gun) in its application. Where one man formerly covered 2 acres per day he now covers 3.6 acres.

We have just finished fertilizing a 101.78-acre field using the HS3 mixture and molasses ash. The HS3 was applied, using the fertilizer gun and the molasses ash by means of the water wheel distributing machine. The HS3 distribution required 28 man days to complete and the ash distribution 12 man days, making 40 man days for the complete application. If the HS2 had been used it would have taken a total of 50 man days, so there is a gain of approximately 10 man days. Trucking and mule expense are about the same in both cases, due chiefly to the concentrated bulk of HS3 and the light weight of the molasses ash.

Taking everything into consideration we find that we are able to apply HS3 and molasses ash a shade cheaper than the HS2 mixture. However, if we had to apply HS3 by hand the remainder would be much in favor of the HS2 fertilizer.

Under the present condition of the world molasses market there seems to be but little probability of selling more than a small percentage of our molasses output. There is always a little of the molasses used for stock food; on plantations favorably situated considerable of their molasses is being applied to their fields at relatively small cost. Many plantations, however, find field application a costly operation. To such plantations this method of molasses burning will not only solve the problem of molasses disposal but will also provide for a considerable amount of the potash requirements of the soil.

Pedigrees of Some of the 1932 Seedlings

By C. G. Lennox and A. J. Mangelsdorf

The 1931-1932 crossing season provided an abundance of new and promising breeding material with which to work. Weather conditions during the tasseling and germinating season were good.

Well over a million seedlings were germinated, from which some 270,000 were selected for potting and subsequent testing in the field.

Some of the more interesting combinations, together with their pedigrees are set forth in the following pages.

Crosses with P. O. J. 2878

P. O. J. 2878 gives promise of being an excellent breeding cane. Its seedlings are, on the whole, remarkably clean, attractive and vigorous.

P. O. J. 2878 was used extensively in crosses this season, both as a male and as a female parent.

Crosses Between P. O. J. 2878 and Thick Canes for Makai Conditions

Cross No. 2523 (and others) 21,000 seedlings	H 109	Lahaina x ?		
	P. O. J. 2878	P. O. J. 2364	P. O. J. 100	Bandjermasin hitam x Loethers
			Kassoer	Cheribon x Spontaneum
		E. K. 28	Parentage uncertain	
Cross No. 1736 720 seedlings	26 C 113		Yellow Caledonia x H 109	
	P. O. J. 2878			
Cross Nos. 705 and 771 990 seedlings	25 C 28		Yellow Caledonia x H 109	
	P. O. J. 2878			
Cross No. 146 and others 3,370 seedlings	Lahaina x P. O. J. 2878			
Cross 1559 1,210 seedlings	P. O. J. 2878 x 27-8101	25 C 14 x Badila	Yellow Caledonia x H 109	

Crosses Between P. O. J. 2878 and Hardy Canes for Mauka and Middle Belt Conditions

Cross Nos. 116 and 240	26 Q 2873	U. D. 88	
1,000 seedlings	x	x	
	P. O. J. 2878	H 109	
Cross No. 1567	Natal Uba		
630 seedlings	x		
	P. O. J. 2878		
Cross No. 136 (and others)	P. O. J. 213	Cheribon	
6,950 seedlings	x	x	
	P. O. J. 2878	Chunnee	
Cross No. 243	U. D. 50	Uba	
572 seedlings	x	x	
	P. O. J. 2878	D 1135	
Cross No. 142	28-4615	Uba	
604 seedlings	x	x	
	P. O. J. 2878	H 456	
Cross No. 187	28-1739	P. O. J. 213	
530 seedlings	x	x	
	P. O. J. 2878	H 109	
Cross No. 246	25 U. H. 13	Uba	
630 seedlings	x	x	
	P. O. J. 2878	H 109	
Cross No. 343	Co. 281	P. O. J. 213	Ashy Mauritius
420 seedlings	x	x	x
	P. O. J. 2878	Co. 206	S. spontaneum

Crosses Between Large-stalk Canes for Makai Conditions

Cross No. 494	H 109		
590 seedlings	x	Yellow Caledonia	
	28-2366	x	
		Badila	
Cross No. 849	25 C 28	Yellow Caledonia	
280 seedlings	x	x	
	Cavengerie	H 109	
Cross No. 1509	27 C 445	Yellow Caledonia	
660 seedlings	x	x	
		H 109	
	20 S 16	Striped Mexican	
		x	
		?	
Cross No. 750	26 C 189	Yellow Caledonia	
490 seedlings	x	x	
	H 456	H 109	
		H 240	
		x	
		?	
Cross No. 453	28-227	P. O. J. 2725	
570 seedlings	x	x	
	H 456	25 C 4	
		H 240	
		x	
		?	

Cross No. 210	28-859	P. O. J. 2364
		x
	x	26 C 270
342 seedlings		
	H 456	H 240
		x
		?
Cross No. 88	Lahaina	
	x	P. O. J. 2364
380 seedlings	29-621	x
		D 117

Crosses Between Hardy Canes for Mauka and Middle-belt Conditions

Cross No. 354	U. D. 50	Uba
		x
	x	D 1135
630 seedlings		
	30-3391	Kassoer
		x
		H 109
Cross No. 369	26 Q 2873	U. D. 88
		x
	x	H 109
360 seedlings		
	K 202	D 1135
		x
		Tip
Cross No. 1619	P. O. J. 213	Cheribon
		x
	x	Chunnee
825 seedlings		
	28-4830	Natal Uba
		x
		H 456
Cross No. 223	Striped Tip	
	x	Uba
400 seedlings	28-4493	x
		H 456
Cross No. 1628	Kassoer	Cheribon
		x
	x	S. spontaneum
255 seedlings		
	Manoa 213	Badila
		x
		?
Cross No. 1532	P. O. J. 2364	P. O. J. 100
		x
	x	Kassoer
530 seedlings		
	28-4488	Uba
		x
		H 456
Cross No. 173	28-2073	P. O. J. 2364
		x
	x	26 C 270
620 seedlings		
	28-4456	Uba
		x
		H 456

Crosses Made at Mapulehu, Molokai, Utilizing the Newly Imported Breeding Canes

Robustum Group

The *robustum* group, imported from New Britain and New Guinea through the efforts of C. E. Pemberton, are clean, hard, sparse-tasseling canes. They tasseled for the first time this season, and were used in many crosses, some of which are shown below.

Cross No. 3326..... 250 seedlings — { 26 C 48 x Mol. 1227 (New Guinea robustum) } { Yellow Caledonia x H 109 }

Cross No. 3234..... 300 seedlings — { 27 8101 x Mol. 1395 (New Guinea robustum) } { 25 C 14 x Badila }

Cross No. 3260..... 300 seedlings — { S. C. 12/4 x Mol. 1194 (New Guinea robustum) } { B 6835 x ? }

Cross No. 3325..... 300 seedlings — { Striped Tip x Mol. 1227 (New Guinea robustum) }

Cross No. 3227..... 300 seedlings — { H 109 x Mol. 1238 (New Guinea robustum) }

Cross No. 3336..... 300 seedlings — { M 313 x Mol. 1296 (New Guinea robustum) } { Striped Tip x ? }

Indian Group

These are slender, vigorous canes from crosses made in India by U. K. Das. They were crossed extensively with local canes with the aim of combining their hardiness with a satisfactory diameter and sucrose content. The following are some typical combinations:

Cross No. 3213..... 300 seedlings — { 26 C 113 x Mol. 466 } { Yellow Caledonia x H 109 } { Purple Mauritius x Katha }

Cross No. 3165..... 300 seedlings — { H 109 x Mol. 680 } { Saretha x S. spontaneum }

Cross No. 3057..... 300 seedlings — { Striped Tip x Mol. 556 } { D 74 x S. spontaneum }

Cross No. 3216	H 109	Barbados 6308
	x	x
300 seedlings	Mol. 1020	S. spontaneum
	P. O. J. 2727	P. O. J. 2364
	x	x
Cross No. 3236		S. W. 3
	x	
100 seedlings		Putlikhajee
	Mol. 352	x
		S. spontaneum
	P. O. J. 2878	
Cross No. 3525	x	Saretha
300 seedlings	Mol. 760	x
		S. spontaneum
	27 C 376	Yellow Caledonia
		x
Cross No. 3217	x	H 109
300 seedlings		Putlikhajee
	Mol. 123	x
		S. spontaneum
	27-8101	25 C 14
		x
Cross No. 3231	x	Badila
300 seedlings		B 6308
	Mol. 928	x
		S. spontaneum

Crosses Made at Mapuleihu, Molokai, Utilizing the Newly Imported Breeding Canes

Australian Group

These are for the most part large-stalk canes from parentages reputed to have good sucrose qualities, together with resistance to certain diseases. This group resulted from crosses made in Australia by C. G. Lennox. They may be expected to give large-stalk seedlings suitable for irrigated conditions.

Cross No. 3168 ..... 300 seedlings	H 109 x Mol. 3934	P. O. J. 2878 x 27 M Q 629	Oramboo x M 1900
Cross No. 3198 ..... 250 seedlings	26 C 189 x Mol. 3656	Oramboo x 28 M Q 298	Oramboo x Q 813
Cross No. 3239 ..... 300 seedlings	Mol. 3726 x H 456	H Q 409 x China	
Cross No. 3235 ..... 300 seedlings	Mol. 1715 x 26 C 188	H Q 409 x 21 N G 22	Yellow Caledonia x H 109
Cross No. 3138 ..... 150 seedlings	H 109 x Mol. 1709	H Q 409 x 21 N G 22	
Cross No. 3510 ..... 100 seedlings	Mol. 3738 x 26 C 270	P. O. J. 2878 x 28 M Q 674	Badila x Q 813
		Yellow Caledonia x H 109	
Cross No. 3167 ..... 150 Seedlings	H 109 x Mol. 3783	P. O. J. 2878 x 28 M Q 674	Badila x Q 813

Q = Queensland.
H Q = Hambledon Queensland.
M Q = Macknade Queensland.
M = Mauritius.
N G = New Guinea.
Mol. = Molokai.

Weather and Crop Relationships at the Honokaa Sugar Company

By U. K. Das

A study of the weather and crop relationships at the Honokaa Sugar Company is of more than passing interest, for the conditions encountered at Honokaa are quite different from those obtained in the other two types of plantations which we have studied heretofore. These two types represent extreme conditions: Pepeekeo an entirely unirrigated plantation where rainfall is generally abundant, though not always well distributed, and Ewa where the deficiency of rainfall is more than made up by a plentiful supply of irrigation water. At Honokaa, the rainfall is neither sufficient to promote continuous growth, nor is it always dependable. It is, nevertheless, the only source of moisture in about half the total area of the plantation. The other half receives occasional irrigation if and when there is enough water available after the fluming operations.

The question naturally arises: Are the weather influences as great at Honokaa as at Pepeekeo and Ewa? If so, can we measure them?

Past History of Honokaa Yields

It may be said without exaggeration that the past crops of the Honokaa Sugar Company have been more exposed to shifting influences than any other place we know of. The constant change of varieties that started way back in 1907 have continued almost to date, with the result that it has been found impossible to segregate a sufficient number of fields growing the same variety of cane over a series of years.

The cultural practices also have varied so much in the past thirty years that in studying the crop yields there always remains a reasonable doubt in one's mind as to whether the trend of increase or decrease in yield between two groups of years is due to changes in the cultural or fertilizer policy or something else.

Coupled with these major disadvantages in disentangling the crop statistics, there is the further handicap imposed by the absence of data as to the amount of irrigation water applied to the fields from season to season.

While, therefore, the absence of sufficient statistics render an exhaustive study of questionable value, there is really no need for such a detailed study of the Honokaa crop data. It will be enough for our purpose if we can show that the weather influences at Honokaa are in general agreement with similar influences at Pepeekeo and at Ewa.

Honokaa Cane Yields

Table I and Fig. 1 show the cane yield per acre from 1909 to 1931. The yields of the Kukuihaele Section (previously the Pacific Sugar Mill) and the

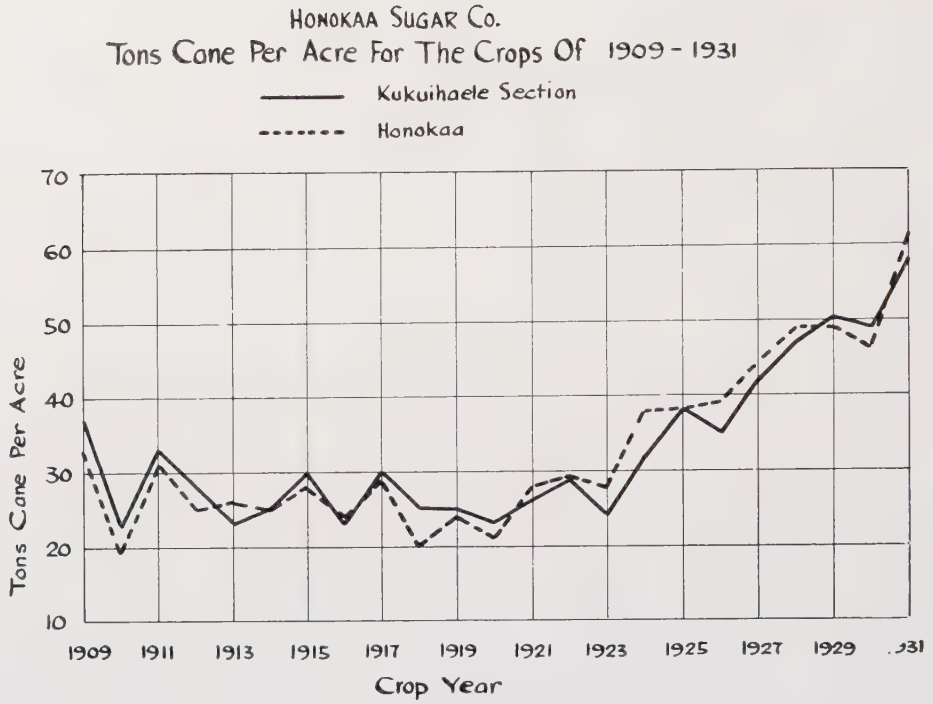


Fig. 1

Honokaa Section fluctuate similarly from year to year. This would naturally suggest that both places are subject to the same influences. The yields are fairly constant up to about 1920, but since then the yields increase progressively. This upward trend in yield since 1920 agrees quite well with a similar trend in yield of the Pepeekeo Sugar Company.

Table II and Fig. 2 show that the yearly fluctuation in yields in the unirrigated section of the plantation (which section should be most subject to weather influences) is similar to the fluctuations in the total area (irrigated and unirrigated) of the plantation. In other words, the irrigated fields have not escaped or overcome those influences that are responsible for the fluctuating yields of the unirrigated section.

Weather Conditions for the High and the Low Yield Crops

We shall grant that the trend of increase in yield is primarily due to cultural improvements or varietal changes, but how shall we explain the random fluctuations from one year to another? It is not conceivable that the cane yield should suddenly jump 8 or 10 tons to the acre one year and then as suddenly drop 8 or 10 tons, due to some cultural or varietal change, for these changes are never so abrupt on a plantation. Furthermore, these very large fluctuations show that they are brought about by factors over which we have no control. Who of us would like to see the yield drop by 8 or 10 tons of cane if we knew how to prevent it?

We are, then, led to suspect that some uncontrollable factor like the weather is responsible for these sudden rises and drops in yields. Our study of the Hono-

HONOKAA SUGAR CO.

Comparing the Average Yields of Unirrigated Section with the Yield of the Entire Plantation.

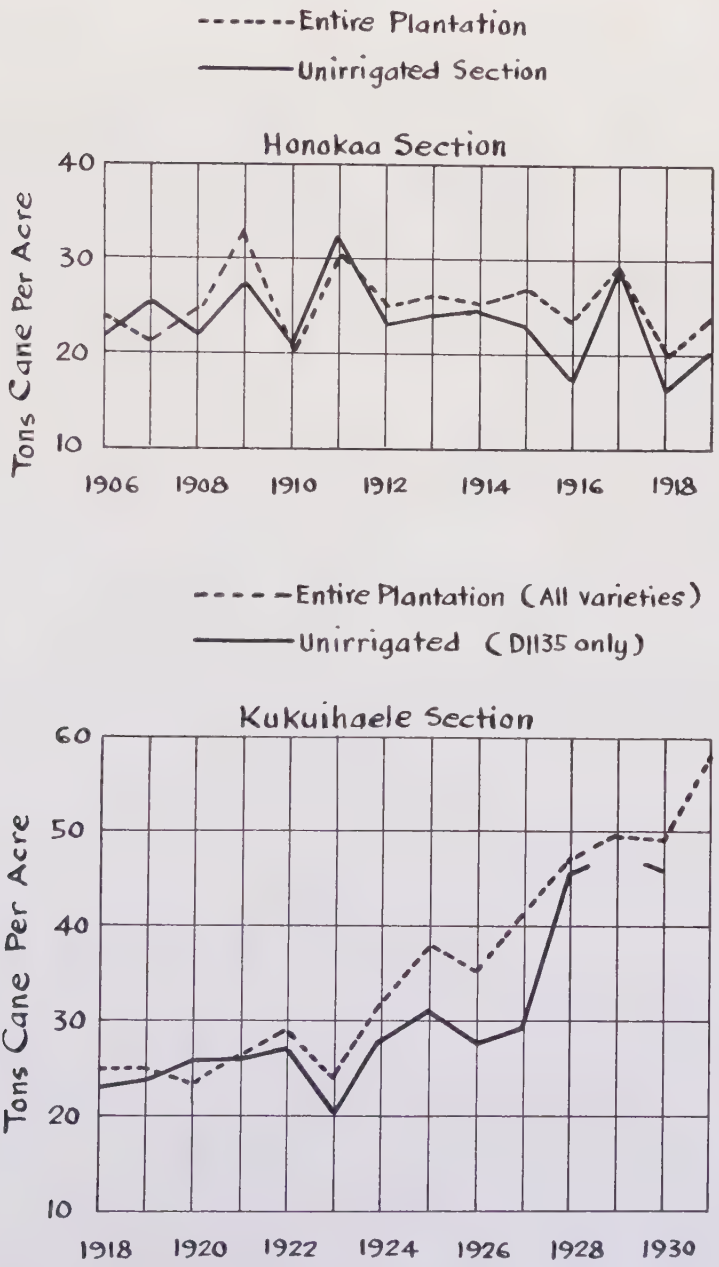


Fig. 2

kaa crop data does show that these random variations are actually the work of weather.

If we take the years prior to 1920, we find that the cane yield was high in 1911 and 1917, that is, there was a sudden increase in yield in these two years as compared with the yield of the years immediately preceding or following. Similarly, the yield was low in 1916 and 1918. How do the weather conditions for the two good crops compare with those for the two poor crops?

Table III and Fig. 3 show that the high yield crops received much more

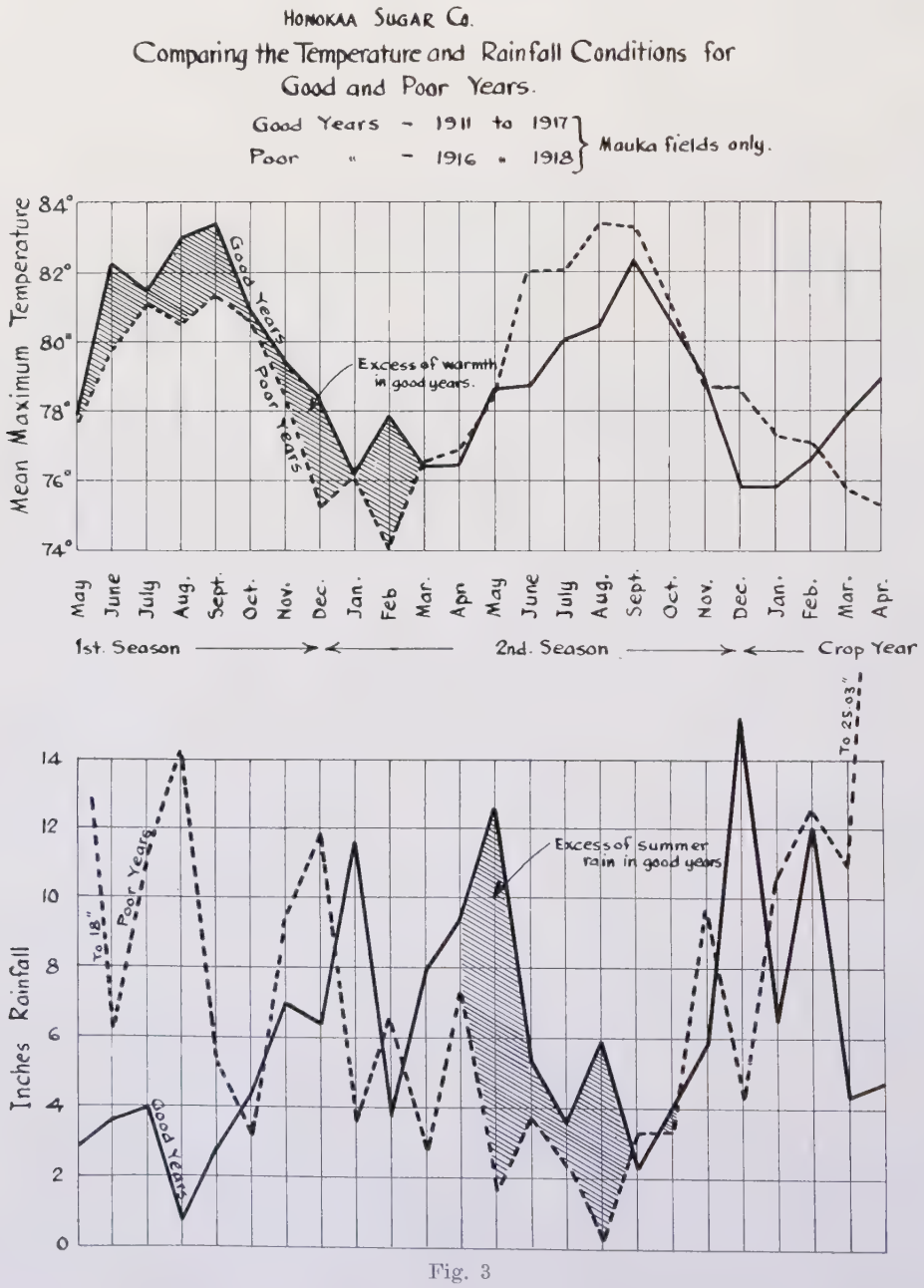


Fig. 3

warmth in the first season of growth than the low yield years. The good crops also received considerably more rain in the spring and summer months of the second season than the poor crops. For high yield, a warm first season would appear to be essential because it is at this period that the foundation of the crop is being laid, it is then that the cane is growing by nature at a rapid rate and therefore can make greater use of warmth.

Also, it appears right that there should be ample water in the second season summer months when the big cane makes increased demand for moisture. Similar differences in weather conditions were found to exist between the high and the low yield crops of Pepeekeo and Ewa.

In studying Fig. 3, one is struck with the fact that it was more in the seasonal distribution than in the total amount of moisture or warmth that the good crops had the advantage of the poor crops. In the good years, warmth and moisture were present when these were needed most. In the poor years, everything came generally at the wrong time.

Temperature Condition in Recent Years

We have seen in Fig. 1 that since about 1920 there has been a progressive increase in the yield of cane at Honokaa. As we stated previously this increasing trend is similar to the one shown by the Pepeekeo yields. In the case of Pepeekeo, we found that the large increases in recent years were due to exceptionally favorable weather conditions. What about Honokaa? Are these large yields due entirely to the progressive changes that have taken place in the agricultural policy of the plantation or do they reflect at least partially the effect of favorable weather?

Fig. 4 is a picture of the temperature conditions at Honokaa for the past 15

Honokaa Sugar Co. (Kukuihaele Station)
Mean Maximum Temperature Expressed as a Plus or Minus
Deviation from the 15 yr.-Average.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1916	−	+	−	−	−	−	−	−	−	−	−	−
1917	−	−	−	−	−	−	+	+	+	+	+	+
1918	+	−	−	−	−	−	−	−	−	−	−	−
1919	−	−	−	−	−	−	−	−	−	−	+	−
1920	−	−	−	−	+	+	+	−	−	−	−	−
1921	−	+	o	−	+	+	−	−	−	−	−	−
1922	−	−	−	−	−	+	+	+	−	−	−	+
1923	+	+	+	+	+	−	−	−	−	−	−	−
1924	+	+	+	+	+	+	+	−	−	−	+	−
1925	+	−	+	+	−	−	−	−	−	+	−	−
1926	+	+	−	−	+	+	+	+	−	+	+	−
1927	+	+	+	+	+	+	+	+	+	Data Missing		
1928	+	+	+	+	+	+	+	+	+	+	−	−
1929	+	−	−	+		+		+	+	+	+	+
1930	+	+	+	−	−	+	+	+	+	+	+	+
1931	+	+	+	+	+	+	+	+	+			−
1932	+	−										

Fig. 4

years from 1916 to 1931. The minuses and pluses show for every month of the last 15 years whether the temperature in that particular month was below or above the 15-year average for the month. The recurrence of minuses around 1920 and the preponderance of pluses in recent years lead us to believe that the temperature conditions have been on the whole very favorable in recent years. This is proved more definitely by the tables and figures that follow.

In order to show the total warmth received by each of the recent crops we have utilized the day-degree as a measure of effective warmth. We have assumed that cane grows very little or none at all below a mean maximum temperature of 70° F. We define a day-degree as one degree of temperature above 70° F. for one day. A month, say January, with a mean maximum temperature of 80° F. will, therefore, have 31 x (80-70) or 310 day-degrees.

If we now assume for the sake of simplicity that the average date of starting a crop in Honokaa is May (some fields are started months before and some months afterwards) and also for the sake of simplicity that the average crop length is 24 months reckoned from the day of starting, then we can calculate from the temperature records the accumulated day-degrees for the various crops (assumed, for instance, that the 1931 crop started in May, 1929, and was harvested in April, 1931).

In Table IV and Fig. 5, the accumulated day-degrees for the "odd year" and

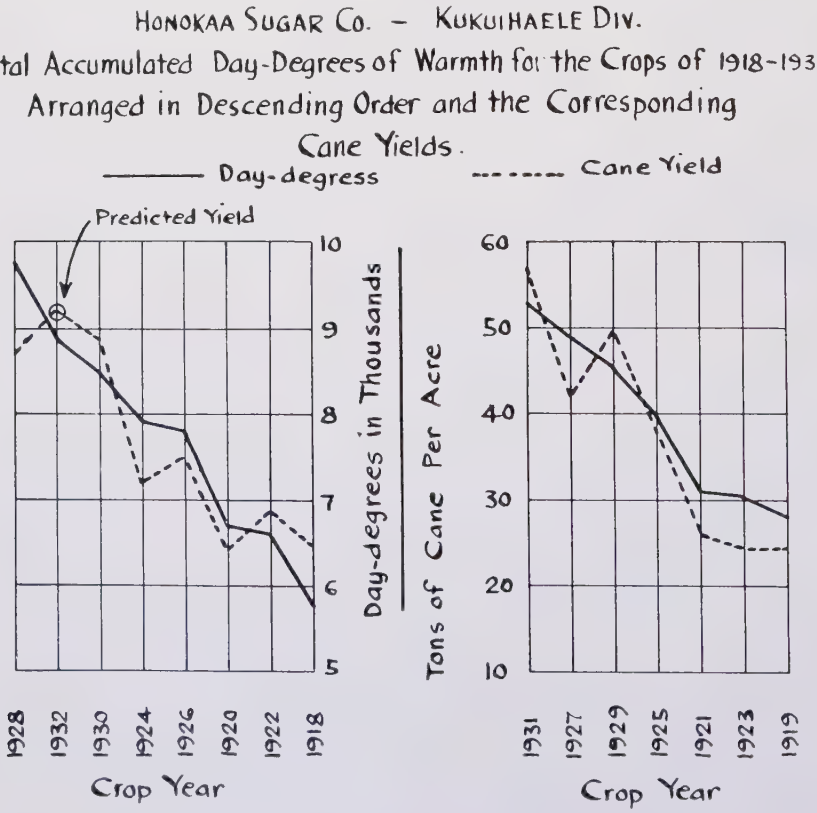


Fig. 5

the "even year" crops are arranged in descending order and the actual yields of cane in the corresponding years plotted against the day-degree figures. The cane yields here shown represent the average yield from all varieties and the entire area of the Kukuihaele section. But as we have seen in Fig. 2, these yields are very similar from year to year to the yields from the Honokaa section. The arguments that we have to offer in this case should, therefore, hold for the whole of the Honokaa plantation.

In Fig. 5, we see a remarkable agreement between total warmth and cane yield. This agreement is still more surprising when it is remembered that the yield figures include all heterogeneous influences such as changes in varieties and in fertilizer and cultural practices. Similar agreements between total warmth and yield have also been found at Pepeekeo. Therefore, there is only one conclusion that we can draw, namely, the influence of temperature is of a preponderating nature on our plantations and that the recent high yields at Honokaa were associated with high temperature. But what about the cultural changes? Are they not reflected in these high yields? We have attempted to answer this question in the following manner.

If we divide the total day-degrees for the various crops by the corresponding cane yield then we obtain comparative figures which show the number of day-degrees required to produce a ton of cane. These "day-degrees per ton of cane" are probably as significant a "measure of the effectiveness of warmth" as the term "gallons of water per ton of sugar" is a measure of the effectiveness of water utilization. Then simultaneously with the improvement in agriculture we should require smaller numbers of day-degrees to produce a ton of cane.

Table V and Fig. 6 do show that Honokaa is getting more tons of cane per day-degree now than it did a few years ago and this we believe is the result of agricultural progress. But this better utilization of warmth alone would not have given these large increases in yields of recent years had not there also obtained a large total of warmth units. Even with the efficiency of 1931, the cane yields in 1919 and 1923 would probably have been poor, because the total amount of heat received by these two latter crops was materially low.

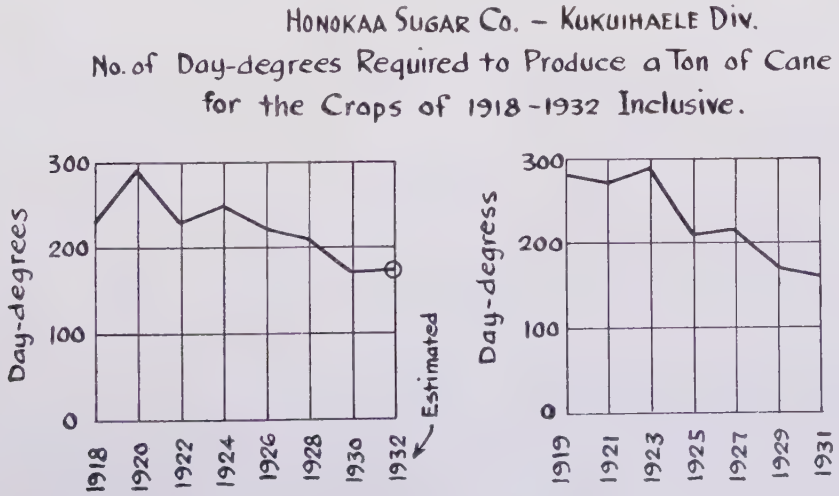


Fig. 6

How do the recent changes in crop length affect the yields? Changes in crop length have taken place mostly in the irrigated section of the plantation; in the unirrigated section the length remains practically the same. Notwithstanding this difference, the recent yields from the unirrigated section show substantial agreement with the yields from the entire plantation. We are, therefore, led to conclude that the changes in crop length that have taken place in some sections of the plantation in recent years have not exercised any influence on yield commensurate with that exercised by the accumulated warmth.

Having now shown that the variations in the yields of recent years are generally associated with conditions of warmth, we can proceed further and show the accumulated warmth for typical high and low yield years month by month from the average date of starting.

In Table VI and Fig. 7 (A and B) are compared the crop conditions of 1928

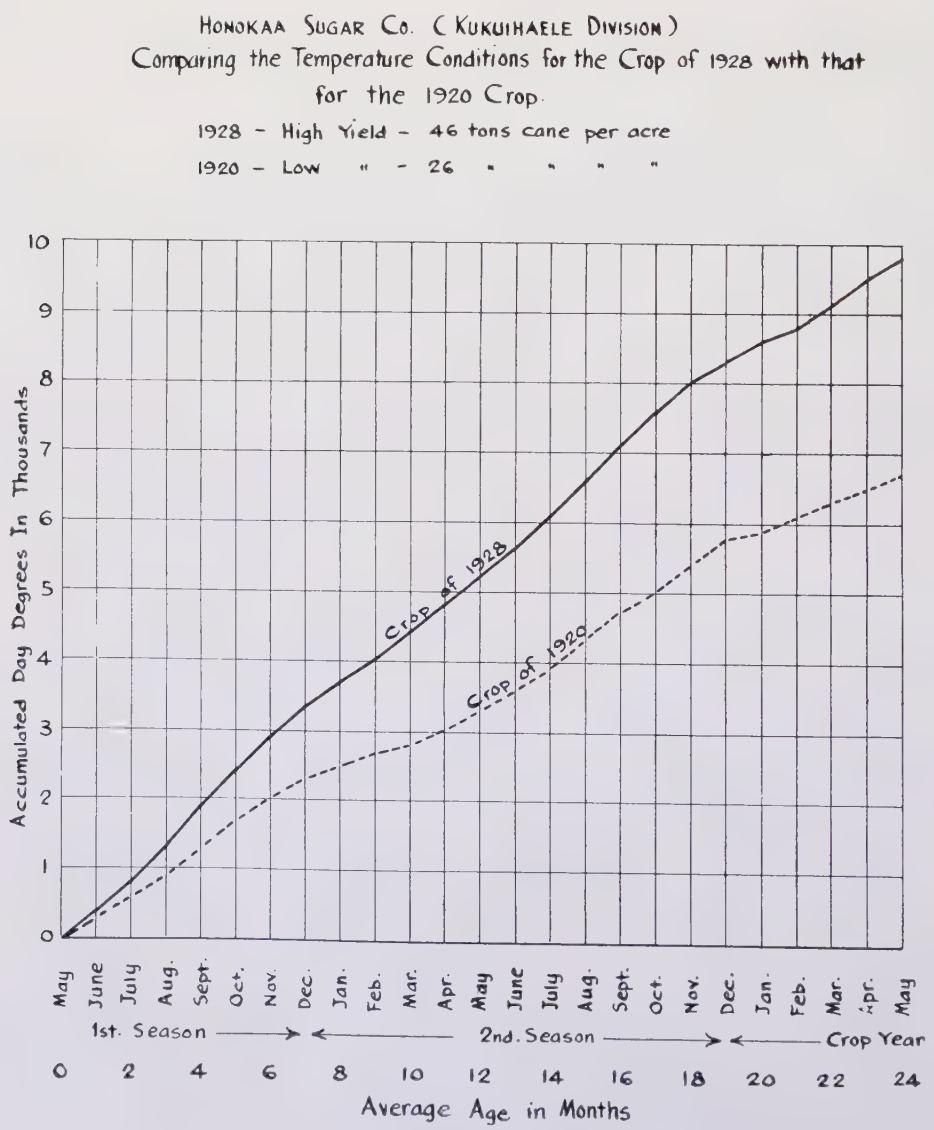


Fig. 7-A

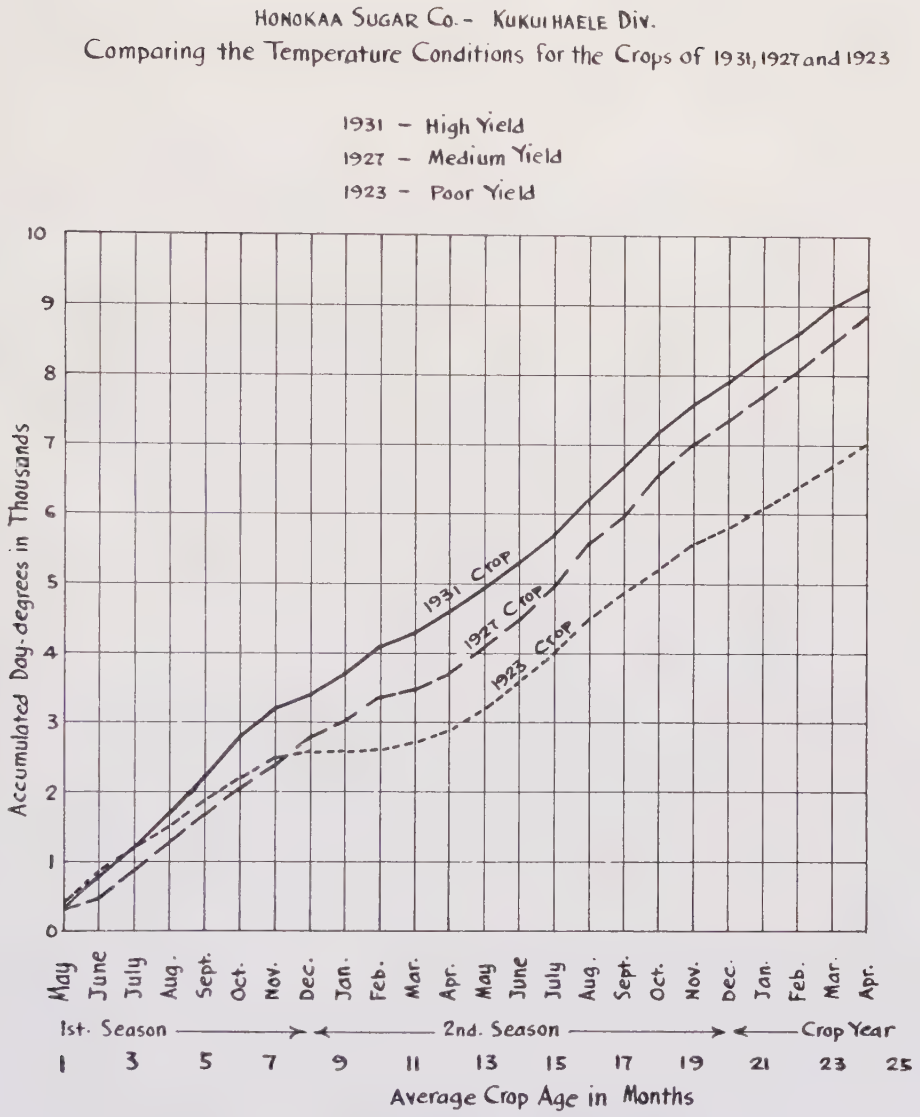


Fig. 7-B

and 1931, high yield years, with the conditions for the low yield years of 1920 and 1923, respectively. The differences in the temperature conditions of the high and low crops are brought out even more strikingly in Fig. 7. At even dates the high yield crops were always ahead of the poor crops by a long margin.

The question may now be raised if we are justified in comparing 1920 with 1928 or 1923 with 1931, for it may be argued that there have been tremendous changes in fertilizer and cultural practices at Honokaa since 1926 and, therefore, the comparison of crops earlier than 1926 with more recent crops is not valid. There was a difference in yield of 20 tons of cane per acre between 1920 and 1928 (same variety in both years). We feel that such a large increase in yield

within the space of a few years could only have been obtained by a combination of favorable factors. It is a fortunate coincidence that together with the big improvements in the cultural policy of the plantation there was also very marked improvement in weather conditions. We find additional support to our view in comparing the conditions for the crops of 1927 and 1931. Both these crops were about equally influenced by recent agricultural changes and they are, therefore, comparable in every respect. The 1927 crop was a fairly good one. The curves in Fig. 7 do show unmistakably that 1927 had better conditions than 1923, but not as good as the conditions for the crop of 1931. The 1931 crop has had the record yield of cane in recent years and we find that it had also the biggest amount of accumulated warmth of any recent odd-year crop.

Similar charts drawn for Pepeekeo and Ewa crops do generally tell the same story. It is our considered opinion that the high yields of recent years were obtained not solely with the help of improved agriculture, but also with the help of exceptionally favorable temperature conditions.

Rainfall Conditions in Recent Years

Table VII and Fig. 8 show the total rainfall in the spring and summer months of the second season for the past 11 crops (Example:—1927 summer rain for the

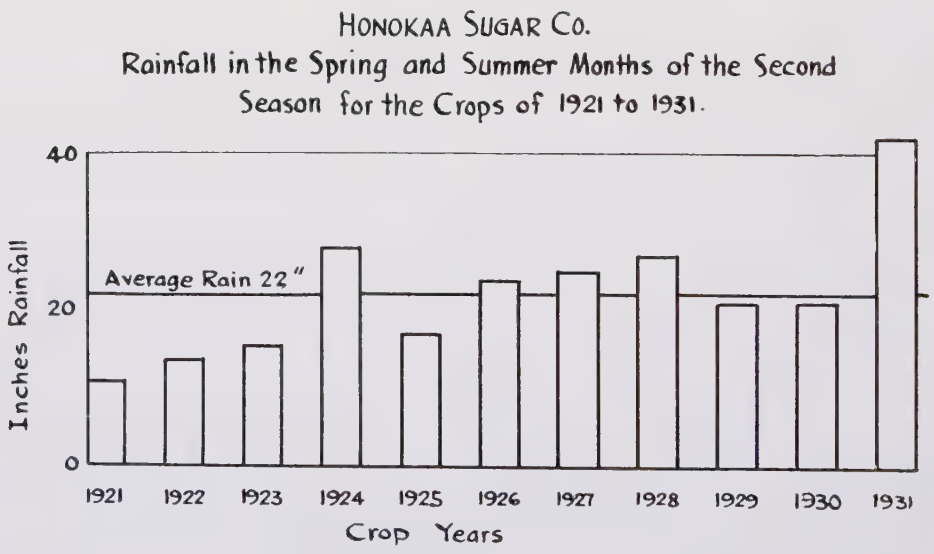


Fig. 8

crop of 1928). We see that the crop of 1931 had almost twice as much rain in the second season spring and summer months as the average for these 11 crops. Therefore, also, as regards rainfall, the 1931 crop was unusually favored. The 1928 crop also had more than average rainfall.

We are, then, justified in concluding that these recent high yields were obtained under very favorable conditions of warmth and moisture. In other words, the good weather made it possible for the plantation to reap the fullest benefit out of

those changes in fertilizer and cultural policies to which alone must be attributed a substantial part of the increased yields.

Rainfall and Juice Quality

In the preceding pages we have shown that the climatic influences on cane yield at Honokaa are the same as at Pepeekeo. Now we shall show that the juice quality is also similarly influenced. (Fig. 9 shows the quality obtained for the crops of 1909 to 1931.)

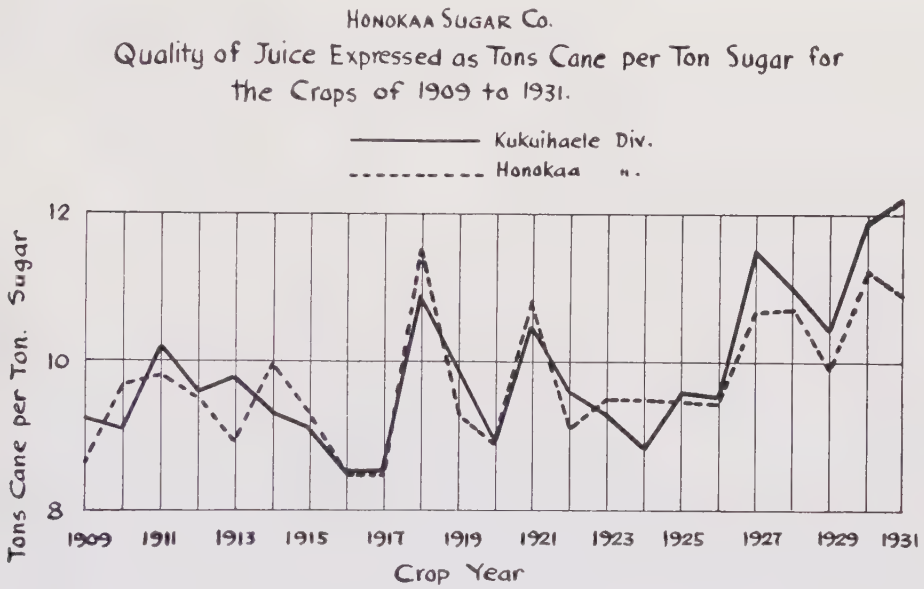


Fig. 9

In our latest study of Pepeekeo we found that juice quality was mainly affected by the seasonal progress of rainfall. In the good juice years the rainfall was ample in the growing months of the second season, gradually decreasing towards harvest time. In the poor years, on the other hand, the second season was dry and the following fall and winter months immoderately wet. In the former case, cane had very likely utilized all easily available nitrogen and completed its vegetative growth by the time it was harvested. In the latter case, vegetative growth might have been arrested by a dry spring and summer. Then, with the advent of a wet fall and winter the cane started belated growth and probably did not reach maturity at the time of harvest.

We find essentially the same picture in comparing the seasonal progress of rainfall for a group of good juice years and a group of poor years at Honokaa. Table VIII and Fig. 10-A show the results.

In the good years the most rainfall was in the second season spring, the harvesting winter had less rain than normal. In the poor years the second season spring and summer were unusually dry and were followed by a wet fall and still wetter winter.

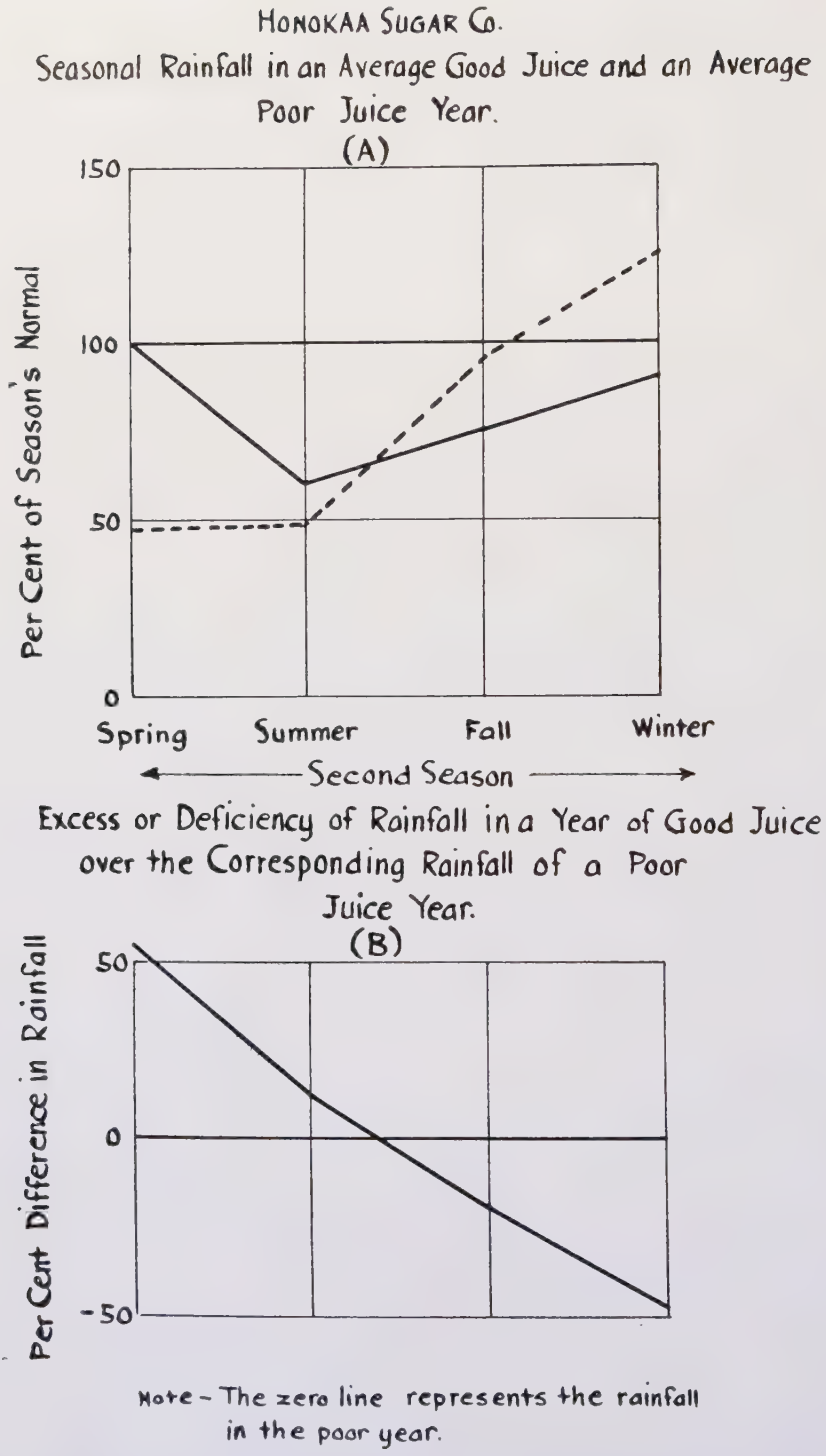


Fig. 10-A. The solid line represents an average good juice year, and the dotted line an average poor juice year.

The difference between a good juice and a poor juice year is further brought out by Fig. 10-B. If the seasonal rainfall for the poor juice year is represented by the zero line, then we see that the good year was wetter in the second season spring and summer when it needed this extra moisture for continuous and active growth and that it was very much drier in the fall and winter months, when this comparative deficiency of moisture was actually conducive to the improvement of juice quality.

Conclusion

This short study supports our previous elaborate studies and further confirms us in our belief that even under the type of conditions represented at Honokaa one can define and measure in general terms the close relation that exists between weather and cane yield.

These series of weather studies bring out very clearly that good and bad weather go in cycles; that while we may justly depend on the good weather to increase our yields we will probably find it difficult to maintain this increase when the bad weather comes.

But what can we do about this weather? We may be asked: How can these weather studies help us to put more sugar in the bag? In reply to this, we may quote from an unpublished report of H. P. Agee:

> Of what good is it to measure our crop yields in terms of weather or day-degrees? To this we might answer: Of what good is it to measure yields in terms of acres of land? But all of us are by now so accustomed to think in terms of *tons per acre* that there is no question that land measurement in relation to yields is a substantial aid to the efficiency in crop production. The reason for this is simply because we have learned to use this type of measurement to our purposes.
>
> The irrigation specialists say: The key to water economy is water measurement. Here again we encounter measurement as an aid to efficient progress. In fact all through engineering and scientific affairs generally, we find progress aligned with ability to measure more precisely the resources, materials, or factors that pertain to the things we do.
>
> Hence it is that we offer weather measurement in relation to crop yield, *tons of sugar per 1000 day-degrees,* as a step forward in attaining a better knowledge of our business, a step that will serve us to the degree to which we learn to think and act in terms of this new type of measurement.

TABLE I

HONOKAA SUGAR COMPANY

Cane Yield per Acre from 1909 to 1931

Crop Year	Honokaa T.C.P.A.	Kukuihaele T.C.P.A.
1909	33.1	37.2
1910	19.5	23.3
1911	31.5	33.3
1912	24.9	28.5
1913	26.2	23.4
1914	25.3	25.5
1915	27.6	29.9
1916	24.0	23.4
1917	29.1	30.0
1918	19.8	24.8
1919	23.7	24.6
1920	20.9	23.5
1921	27.7	26.3
1922	29.5	28.9
1923	27.9	24.5
1924	38.0	31.5
1925	38.2	38.0
1926	38.6	35.0
1927	43.7	41.5
1928	48.9	47.0
1929	48.8	49.7
1930	46.2	49.0
1931	60.9	57.7

TABLE II

HONOKAA SUGAR COMPANY

Cane Yields from Unirrigated Sections of Honokaa and Kukuihaele

Honokaa Section (All Var.)		Kukuihaele Section (D 1135 Only)	
Crop Year	T.C.P.A.	Crop Year	T.C.P.A.
1906	22.2	1918	23.4
1907	25.5	1919	24.4
1908	22.2	1920	26.2
1909	27.4	1921	26.1
1910	20.6	1922	27.5
1911	32.3	1923	20.0
1912	23.3	1924	27.5
1913	23.8	1925	31.1
1914	24.6	1926	28.1
1915	23.0	1927	28.7
1916	16.8	1928	46.4
1917	29.3	1929	...
1918	15.8	1930	46.4
1919	20.3	1931	...

TABLE III

Conditions of Temperature and Rainfall for High and Low Yield Crops

Good Years: 1911 and 1917
Poor Years: 1916 and 1918

		Good Years		Poor Years	
		Inches Rainfall	Mean Maximum Temp. F.°	Inches Rainfall	Mean Maximum Temp. F.°
1st Season—	May	2.87	77.9	17.94	77.6
	June	3.71	82.3	6.08	79.8
	July	4.08	81.5	11.02	81.1
	August	.70	83.0	14.21	80.5
	September	2.75	83.4	5.42	81.4
	October	4.15	80.9	3.23	80.6
	November	7.00	79.4	9.44	78.5
	December	6.38	78.4	11.86	75.2
2nd Season—	January	11.65	76.1	3.56	76.1
	February	3.73	77.9	6.49	74.0
	March	6.95	77.4	2.93	76.5
	April	9.33	77.4	7.40	76.9
	May	12.53	78.6	1.86	78.4
	June	5.25	78.7	3.74	82.0
	July	3.46	80.0	2.19	82.1
	August	4.90	80.4	.26	83.4
	September	2.17	82.3	3.25	83.3
	October	3.98	80.7	3.42	81.2
	November	5.87	78.9	9.71	78.7
	December	15.19	75.8	4.23	78.7
Crop Year—	January	6.53	75.8	10.63	77.3
	February	12.02	76.5	12.45	77.1
	March	4.30	77.9	10.82	75.8
	April	4.65	78.9	25.03	75.3

TABLE IV

Accumulated Day-degrees for the Crops of 1918 to 1931

Crop of	Accumulated Day-degrees
1918	5721
1919	6888
1920	6738
1921	7083
1922	6559
1923	7034
1924	7962
1925	7965
1926	7800
1927	8908
1928	9820
1929	8551
1930	8533
1931	9307

TABLE V

Day-degrees per Ton Cane for the Crops of 1918 to 1931

$$\text{Day-degrees per Ton Cane} = \frac{\text{Total Accumulated Day-degrees}}{\text{Tons Cane per Acre}}$$

Crop of	Day-degrees per Ton Cane
1918	231
1919	280
1920	287
1921	269
1922	227
1923	287
1924	253
1925	210
1926	223
1927	215
1928	209
1929	172
1930	174
1931	161

TABLE VI

The Month to Month Progress of Accumulated Warmth for Good and Poor Crops

	"Even Year" Crops		"Odd Year" Crops		
	Good Yield 1928	Poor Yield 1920	Good Yield 1931	Med. Yield 1923	Poor Yield 1927
1st Season—					
May	384	251	329	372	270
June	828	551	800	783	543
July	1336	883	1200	1161	896
August	1860	1264	1727	1518	1262
September	2355	1660	2243	1863	1694
October	2876	2035	2776	2229	2134
November	3305	2338	3169	2478	2437
December	3674	2518	3439	2627	2809
2nd Season—					
January	4024	2673	3740	2627	3048
February	4416	2841	4054	2627	3378
March	4835	3039	4349	2680	3530
April	5216	3285	4586	2929	3692
May	5638	3561	4912	3227	4076
June	6091	3897	5281	3590	4520
July	6593	4272	5743	4040	5028
August	7123	4653	6193	4471	5552
September	7591	5022	6697	4855	6047
October	8003	5419	7202	5246	6568
November	8321	5758	7616	5561	6997
December	8569	5885	7948	5849	7368
Crop Year—					
January	8842	6074	8298	6119	7716
February	9097	6287	8620	6385	8108
March	9469	6513	9001	6701	8527
April	9820	6738	9307	7034	8908

TABLE VII

Total Rainfall in the Spring and Summer Months for the Crops of 1921 to 1931

Crop of	Total Rainfall in Inches
1921	11.19
1922	13.75
1923	14.38
1924	28.28
1925	17.51
1926	24.15
1927	24.52
1928	27.33
1929	20.95
1930	21.28
1931	42.16

Average for (1921 to 1931) = 22.3 inches.

TABLE VIII

HONOKAA SECTION—HONOKAA SUGAR COMPANY

Seasonal Progress of Rainfall in a Group of Good and a Group of Poor Juice Years—Rainfall Expressed as Percentage of the Season's Normal.

Good Years—1916, 1917, 1920, 1929
Poor Years—1914, 1918, 1921, 1930

2nd Season—	Good Years	Poor Years	Difference Good Year-Poor Year
Spring	101%	47%	+ 54%
Summer	61	48	+ 13
Fall	77	96	— 19
Winter	93	127	— 34

Plant Wilt and Its Relation to the Rates of Water Supply and Water Demand

By H. A. Wadsworth

That the physical symptoms of wilt are the results of insufficient moisture in the leaves and stem of a plant goes without saying. And yet some of the reasons for these symptoms are not self evident.

As everyone knows, moisture is lost from the leaves of a plant by transpiration while water is added to the leaves by the translocation of soil moisture from the soil to the aerial plant parts. The many ingenious and complicated hypotheses, which have been developed to explain this translocation of moisture from soil to leaves, need not concern us. At best it can only be said that the process is not fully understood.

Be that as it may, the fact remains that water is continuously being lost from the leaves and continuously being replaced. The question of rates is at once apparent and deserves most serious consideration if a true understanding is desired.

For illustration, let it be supposed that a mature cane plant is being grown in nutrient solution or tap water after the manner of Dr. Lyon's spectacular experiment. Here the supply of "soil?" moisture is limitless and of equal availability throughout the life of the plant. The *rate* at which water may be moved from the reservoir, however, is not at all without a finite limit. Every drop of water removed from the solution must be absorbed by the roots, surely a process which takes some time, and conveyed against the resistance to flow in the minute tubes of the vascular system within the cane stick. In any hydraulic system the conveyance of water takes time. The analogy between the tracheids in the stick and a bundle of minute pipes may be far-fetched but it seems to be physically sound.*

From this reasoning one might suppose then that in the conditions of Dr. Lyon's experiment, water should be abundantly available in the leaves of the cane regardless of the demand upon the leaves for water until a certain maximum demand was reached. If the conditions of the environment such as excessive light and heat demanded a greater supply than this maximum, water would be lost from the stored water in the leaf tissue, the familiar symptoms of wilt being evident. Under such conditions we would have cane evidencing all the symptoms of wilt although growing in nutrient solution.

Here the question of rates is of most importance. The rate at which water is required for transpiration in any given plant depends upon the intensity of sunlight, the temperature, the relative humidity and, to a minor extent, upon wind velocity, while the rate at which water is available to the leaves depends upon the number of absorbing roots and the hydraulic characteristics of the conveyance

* A recent thesis at Stanford was devoted to "The hydraulics of sap."

system. Naturally, if the rate of loss from the leaves exceeds the rate of supply, flaccid tissue must result and plants exhibiting flaccid tissue are said to be wilted.

It is doubtful if a cane plant growing in the environment of Honolulu and in a nutrient solution would ever exhibit the customary signs of wilt due to this difference in rates.* The character of the vascular system indicates a great capacity for water conveyance, while Dr. Lyon's photographs show an amazing development of absorbing roots. Moreover, the cane leaf is peculiar in its ability to retain its form and apparent turgor.

It is apparent that "wilt" from the hypothetical conditions suggested above is quite temporary and will disappear when conditions so adjust themselves that the demand for water from the leaves is less than the potential supply from the vascular system. The setting of the sun with the resulting lowering of temperature and an increase in relative humidity ordinarily restores complete turgor when temporary wilt has been experienced. Examples of temporary wilt are quite common elsewhere; the most spectacular being the behavior of the apricot tree in the Santa Clara Valley in California during the heat of the summer. In many cases the trees show every sign of vigor by crisp, normally held leaves until the middle of the afternoon when all appearances of wilt become evident. Recovery usually takes place at sundown. And this process may continue during the hottest months, although the orchard may be continuously and abundantly irrigated.

Wilt of this type is naturally called "temporary wilt" and depends upon the relation between the demand for water, by the factors making for transpiration, and the rate at which water may be supplied by the roots and vascular system. The relative soil-moisture content at the time of wilt does not need consideration since such wilt may occur at any soil-moisture content. Although temporary wilt may not be common in cane fields in Hawaii, and we have little evidence on the point, the conception of temporary wilt is stressed here to emphasize the point that a question of rates is involved.

When observations are made upon a plant rooted in soil other complications are added. Water is no longer available in limitless amounts as in the case of water culture because as is well known a soil may be too dry to permit normal turgor and we say once more that the plant is wilted. The conception of rates again applies but in this case wilt may be caused not by a temporarily excessive demand from the leaves but by an insufficient rate of supply. And this insufficient rate of supply is due to the fact that whatever moisture may still be in the soil, is so tightly held to the soil grains that it can be torn loose and absorbed at only a very slow rate. Wilt of this type is called "permanent wilt." Permanent wilt can only be corrected by adding water to the soil. By so doing one increases the rate at which water is made available to the roots and consequently to the leaves.

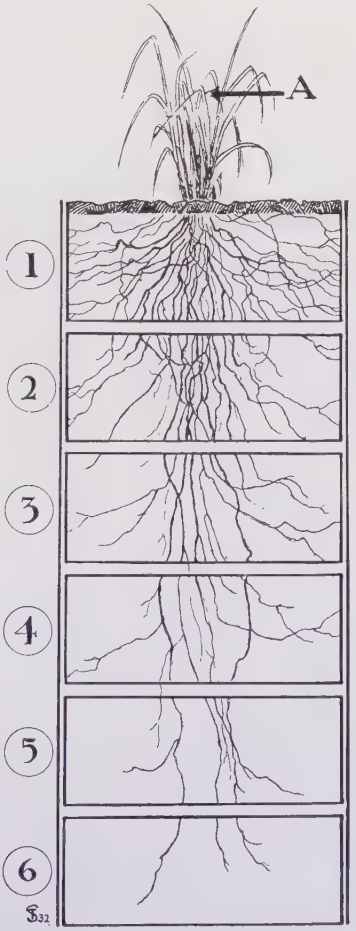
Since both temporary and permanent wilt are indicated by the same symptoms, it is necessary to distinguish carefully between them. Temporary wilt has already been described. An arbitrary definition holds that a plant suffers from permanent wilt when that plant fails to recover turgidity within twelve hours when the loss of water from the leaves is essentially reduced to zero. As indicated above, this

* Wilt symptoms were observed in one of the water culture plants grown by H. L. Lyon.

condition may be brought about by placing the plant in the dark, by lowering the temperature and by increasing the relative humidity.

The argument is simple enough if plants are grown in containers that are small enough, in view of the expected root spread, to permit complete root permeation. In such a case, every cubic inch of soil would be invaded by feeding roots in about equal abundance. Consequently, one would expect different points within the soil mass to reach the moisture content at which water is insufficiently available at about the same time. A large part of the work involving the conception of permanent wilting has been done with potted plants.

When plants grown in the field are considered, no such complete permeation of roots is possible. Some plants are characterized by deep roots, while others are surface feeders. Nor from an inspection of the root distribution as evidenced by trenches cut across the rows would one expect that every cubic inch of soil was invaded by a feeding root. Moreover, although most of the roots of a cane plant in the field are to be found in the upper two feet, significant amounts may be found in the third and relatively smaller numbers in the fourth, fifth and perhaps sixth foot.



This distribution is diagramatically shown in the illustration. If the entire soil mass is wet at the beginning of observations, every active root in the entire depth is a potential source of supply and the rate of supply is, as in the case of the water culture, determined by the total number of roots and the hydraulics of the vascular system.

The rate at which water is being lost from the leaves seems to be determined entirely by environment. For example, some evidence leads us to believe that a mature cane plant transpires about 15 pounds of water per day under the conditions of the dry side of Oahu. Let it still further be supposed that this loss of 15 pounds per day is uniform throughout the 24-hour period. Everyone who has worked with cane knows that this is not the case and that transpiration is much greater during the day than during the night. But the supposition of uniform transpiration makes a logical step in the reasoning.

Under the conditions, then, water is being lost at *A* in the diagram at a rate of 15 pounds per day, this amount being taken from the soil invaded by the roots. It may also be assumed that the rate of loss from each foot in the diagram is about proportional to the number of roots in each. Consequently, if the diagram represents anything like the truth, most of the 15 pounds would come from the first two feet, much less from the third, and so on.

If the soil as shown in the diagram is uniform, the first two feet contain no more soil moisture than the next two, and yet moisture is being lost from them at a rapid rate due to the heavy root concentration. At some time a day will come when the soil moisture in the first two feet will be so far reduced that the roots in this zone cannot contribute their normal quota to the 15 pounds required daily, and the demand upon the roots in the third foot will be increased. Here, however, the root distribution is scanty and although ample soil moisture would be available by vigorous root extension in this stratum, the cane plant seems to prefer to suffer than to modify its normal rooting habit. Consequently, the lower depths fail to meet the added demand for water because of the exhaustion of available moisture in the surface two feet. The demand of 15 pounds per day continues; the available rate of supply is less than this amount for reasons which have been given; plant tissues become flaccid. Since growth either by cell division or cell enlargement cannot occur with flaccid tissue, growth ceases. Nor can growth be resumed until such a percentage of the soil mass has been supplied with water, that the roots within it can deliver water to the leaves at our hypothetical rate of 15 pounds per day.

If one secures samples for soil-moisture determination in the first two feet in the diagram, the soil-moisture content at the time of growth cessation should be approximately equal to the percentage of moisture in the soil at the time of wilt as determined by the use of potted plants in the same soil. This may primarily be due to the fact that the cane plant seems to carry a compact root system. If the roots spread thinly through large areas and to great depths, an insufficient rate of supply of moisture might be evidenced at a high average soil-moisture content as determined by soil sampling. For in this case, a given soil sample might contain a large amount of soil that had not been depleted by root action. Although it would not be generally supposed that fruit tree roots completely invade every

cubic inch of soil, such must be essentially the case for much evidence indicates that such trees as apricots and prunes exhibit signs of permanent wilt when the soil moisture, as determined by field samples, approaches the figure indicative of permanent wilt with potted plants grown in similar soil.

In San Diego County, orange groves are frequently irrigated on the basis of results from soil-moisture determinations. An irrigation is ordered when the average soil moisture percentage in the upper three feet of soil falls dangerously near the permanent wilting percentage.

The argument so far advanced has been based upon the conception that the transpirational demands are constant during the 24-hour period. Evidently this conception is not in accord with the facts and the argument should be re-examined in view of the fact that transpiration during the night is practically zero and may approach 2 or 3 pounds per hour for a mature stool during the heat of the day.

If we again use the diagram as an illustration, the loss by transpiration at *A* becomes a variable and may range from zero, to, say, 2 pounds per hour. At high moisture contents all the soil strata hold their maximum amounts and the rate of supply in view of the activity of all the roots is sufficient to satisfy the peak demands of the afternoon. Consequently, growth is continuous during day and night. It is evident, however, that a time will come when the rate of supply, in view of the inevitable depletion of moisture in the more heavily rooted depths, will be insufficient for the periods of peak demand, although sufficient for the periods of darkness. Under such conditions of extreme differences between day and night temperatures, one might expect growth to be continuous and uniform during periods of high moisture content for in that case full turgidity might be expected. At lower moisture contents, say, when the rate of supply by the roots was sufficient to maintain turgor during the night but not during the day, one might expect elongation during the night and curtailed growth during the day. And at still lower moisture contents the period of darkness may be too short to allow for the full recovery of the flaccid tissue of the preceding afternoon. Consequently, no growth during either day or night could be expected.

It should not be thought from this discussion that the only loss occurring from wilting plants is a loss of potential growing time. Sometimes a condition of wilt at a particular stage of growth sets up a resulting effect which greatly reduces yields. This point has been most completely explored with cotton. If this crop is allowed to experience wilt at the time the bolls are forming, an abnormally great dropping of partly matured cotton bolls may be expected. Any such possibility with sugar cane is not recognized at present.

Summary

1. This paper is free from detailed results of experimental data. It purports to be no more than a discussion of some of the factors involved in the wilting of plants, particularly sugar cane.

2. Wilt is described as the natural result of a loss of water from the plant at a greater rate than the rate of supply of water from the soil.

3. The same conception of rates seems to apply to both temporary and permanent wilt. An attempt is made to differentiate between them.

4. Since wilt is a sign of flaccid tissue and since cane plants characterized by flaccid tissue cannot elongate normally, if at all, the practical value of precautions against wilt is evident.

5. Although an ample supply of soil moisture may be available in the third and fourth and fifth foot of soil, the cane plant apparently prefers to wilt and eventually die than to modify its normal rooting habit by developing extensive root systems in these lower strata.

The Hilo Forest Reserve

By L. W. Bryan
Forest Supervisor

Foreword

The following report covers the work accomplished in the Hilo Forest Reserve during the past ten years by Forestry Unit No. 3 in cooperation with the Territorial Division of Forestry. The work of the unit is so thoroughly interwoven with that of the Territorial Division of Forestry that it is impossible to segregate the activities of one from the other, and no attempt will be made to do so in this report.

Organization

Forestry Unit No. 3, which embraces all of the area known as the Hilo Forest Reserve, was organized in 1921 by the plantations on the Hilo coast, which interests have since maintained it. This reserve includes both government and private lands, about 60 per cent of the area being owned by the government, while the remainder is controlled by the plantations concerned.

In our work, little attention has been paid to the ownership of the various lands, the object always being to carry through to completion whatever work was necessary for the good of the reserve as a whole, regardless of where this work had to be done.

All work in the Hilo Forest Reserve is done under the supervision of the writer, who acts as forest supervisor for the unit and, at the same time, directs the work authorized by the Territorial Division of Forestry.

Four ranger stations are maintained in this reserve and one forest ranger, one nurseryman and four tree planters are regularly employed. In addition, during the slack season, the plantations usually put on, for such periods as they can be spared, a number of extra men who plant trees and do other forestry work.

There is now in operation 15 miles of telephone line connecting the various stations and many miles of trails are maintained within, and adjacent to, the reserve area. Telephones and trails are of vital importance to the reserve. They are not only essential for routine procedure but, in cases of emergency such as forest fires, they are indispensable. Both must always be in running order and constant care and attention are required to keep them so.

Five rain gauges and two temperature recording stations are maintained within the reserve. Records obtained therefrom have already proven of value.

In the land of Honomu, within the forest reserve, a small park, embracing the area around Akaka Falls in the Kolekole Gulch, has been developed. Akaka is the highest waterfall on the Hilo coast, having a sheer drop of 418 feet. It may be reached by trail from the end of a new automobile road. This park has been

improved principally through the efforts of the Honomu Sugar Company and constant care is necessary to keep the grass cut and the paths clear. This area is very popular with tourists and is also well patronized by local people. A small house and fireplace have been constructed at a vantage point overlooking these falls.

Survey

One of the first steps undertaken was to secure a survey and map of this reserve, for, previous to 1921, this area had never been entirely marked out on the ground. The survey, which was carried through by the Territorial Survey Department, assisted by Unit No. 3, and which required about six months to complete, showed that this reserve embraced an area of 111,750 acres, making it the largest in the Territory. Since 1921, several additions have been made, bringing the total area up to 122,782 acres.

This reserve, which covers a strip about 30 miles long with an average width of 10 miles, extends, unbroken, from the land of Waiakea on the south to the Hilo-Hamakua boundary line on the north. The lower or makai line follows near the 1,700-foot contour and the upper or mauka boundary is above 5,000 feet.

While the boundary survey was being made, considerable data were secured concerning such matters as existing trails, trespass of cattle, areas in need of planting, etc., etc. All of this information was used in the preparation of a status map, showing the condition of each land within, and adjacent to, the reserve.

Fencing

During the course of the survey work, it was discovered that in several places, stock was being permitted to trespass within the reserve, so immediate steps were taken to secure protection against this nuisance by constructing several miles of new fence. A considerable part of this fencing was accomplished with the co-operation of owners of adjacent lands. During the period covered by this report, 23 miles of new fence have been built and fences previously constructed have been kept in repair. There is now a total boundary length of 90 miles, 56 miles of which are protected by stock-proof fences. All fences are gone over at least once a month, for constant patrol and frequent inspections are necessary if this area is to be kept in a stock-free condition.

Animals

After fencing, it was found that a considerable population of wild or semi-wild animals still inhabited the reserve. In order to rid this area of them, it was found necessary to shoot all those that could not be removed by other means. During the past ten years, there have been reported as killed within this reserve 89 head of wild cattle, 1155 wild pigs and 88 wild goats. There will always be a few wild cattle but they have been reduced to such a small number that they now do very little damage. Pigs do not seem to be nearly as plentiful as in former years, but they still do some damage in certain sections. Goats are only found on, or adjacent

to, the lava flows on the southern end of this area. These animals fortunately do not like the thick, wet jungle and seldom enter except along the outer edges in extremely dry weather.

Trees

Tree planting was commenced during the latter part of the first year and has continued ever since. Up to date, we have planted out 927,063 trees on, or adjacent to, this reserve and in addition have supplied and supervised the planting of 20,979 trees for windbreaks along the seacoast. We have also furnished many thousands of fruit and ornamental trees which have been planted out on plantation lands.

At the start, very little was known regarding just what species of trees were suited to a given area and mistakes were unavoidably made. In order to try and determine which species were best suited to a given locality, a number of arboreta were established at different locations. These arboreta were carefully laid out, mapped and an accurate record kept of the different species planted therein. Up to date, we have experimented in this way with nearly 500 species. Many of them have proven to be unsuited for our work and have been discarded, while others show considerable promise. Those which have shown up to best advantage in our arboreta are being planted out in considerable numbers in our regular reforestation work.

In our plantings within the reserve, our aim has been to introduce species that would eventually spread themselves and, of course, at the same time, provide a suitable watershed covering. Among other trees, several members of the genus Ficus have been used with success. Many of them have now reached fruiting size and from those that produce fertile seed (*Ficus macrophylla* and *F. rubiginosa*), we can soon expect natural reproduction to become evident. Other species, such as *Ficus nota,* are now fruiting but their pollinating wasps are not present so it will be impossible for them to spread naturally until such a time as the proper wasps have been introduced.

In our plantings below the reserve area, we have tried to employ such trees as can some day be utilized by the plantations for fuel, lumber and the many other uses where wood is indicated. Several different kinds of timbers are now being tested as fence posts, some treated and some untreated. Some of the trees planted for utility purposes, during the early part of the period covered by this report have now reached a size sufficiently large to be cut and many of them are already being used for fence posts, firewood, flume props, etc.

In the camp areas, the planting of fruit trees has been encouraged in the hope that the fruit which they will some day supply may prove a valuable addition to the laborers' diet.

Whenever possible, assistance has been rendered in the beautification of parks, camps, mill grounds, residential premises, roadsides, etc. In several cases, formal planting plans have been prepared and the necessary planting material furnished to execute them.

At the start, a survey showed that there were about 16,000 acres within the Hilo Reserve in need of reforestation. This does not mean that all of this area

must be planted by hand for, in some sections, the native forest is coming back of its own accord and, as already stated, we may reasonably expect a certain amount of natural reproduction by species already planted.

Planting along the mauka boundary of this reserve has presented an entirely different problem from that which we found makai. The mauka boundary is over 5,000 feet in elevation and has less rainfall than is found at most of our lower levels. Many different species have been tried in this section, a few of which have proven successful. The rate of growth is slow, due to cold nights throughout the year. Several species of temperate zone trees do well but have the disadvantage of being deciduous, losing their foliage during the winter months. We have much to learn regarding what is best to plant in our mauka lands and are going about the solving of this problem in a cautious manner. We do not propose to plant out large numbers of any given species until, through actual trial, it has proven to be what we want. It is encouraging to note that in several sections of our mauka lands, the native koa (*Acacia koa*) has given good results and in some areas has come back naturally.

The plantings made by Puu Oo Ranch, in the mauka section under the requirements of their leases with the different plantations, have proven of value in an experimental way. They have planted out 14,000 trees representing 52 different species. From these plantings, we have gained considerable knowledge regarding the habits and possible value of the species tested.

Three tree nurseries directly connected with this unit have been established and continuously operated. One is maintained by the unit at our Nauhi Gulch Station at 5,100 feet in the land of Honohina. Here are raised trees for planting in the mauka lands and, conditions being different, we have been forced to adopt methods somewhat different from those employed in the low lands. This nursery and station is entirely a unit project. The other two nurseries have been independently maintained by the Hilo Sugar Company and Honomu Sugar Company, respectively.

The Territory maintains a nursery in Hilo. At the start, it was apparent that this nursery, with its then small force and meager appropriations, could not begin to supply the unit's demand for planting material. In order to be assured of a steady supply of trees to meet our needs, the unit employed two additional men and placed them in this nursery. This arrangement proved satisfactory and through it we have secured adequate planting material.

During the period covered by this report, there have been raised and shipped 2,119,599 plants from these four nurseries divided as follows:

Hilo Nursery (Government)	1,876,175
Nauhi Gulch	19,062
Honomu	91,747
Hilo Sugar Co.	132,615
Total	2,119,599

In addition to the nursery work at Nauhi Gulch Station, we have experimented with a large number of plants among which have been some 60 different varieties of temperate-zone fruit trees. Several of the latter are now producing fruit which

appears to be at least equal to that imported from the mainland. Our experiments would seem to indicate that this mauka country is well suited to the cultivation of such fruits as apples, pears, quinces, plums, cherries, etc., and there is sufficient area available to produce enough fruit of the kinds named to supply all island markets. Propagating material has been secured from some of the most promising of these trees and about 2,000 young plants have been rooted and distributed.

Proper planting methods and care of young trees after planting has been one of our important problems and it is only by experimentation that we have achieved a technique that seems satisfactory. We do not strive to plant out a large number of trees in order to make a showing. Rather we lean in the opposite direction and plant out new trees only after those previously planted have been cared for. A recent impartial check of some of our older plantings showed that nearly 90 per cent of those planted were alive.

As one method of reforestation, we have tried direct broadcasting of certain species of trees but with only a small degree of success. Occasionally, we find trees growing as a result of our efforts but they are not common except in cases where a seed-bed has been first prepared for certain rapid-growing species. Airplane sowing of seed has not been tried in this reserve. However, on an adjacent reserve considerable success has been attained by employing this method.

Law Enforcement

When we first started in to fence our boundaries, we found many cases of flagrant violations of our forestry laws and rules, mostly due to ignorance. Warnings were issued, forest signs posted, and people in general educated and informed regarding the laws and, as a result, violations have become less numerous. At present, we have only an occasional illicit pig hunter to deal with. During the past ten years, we have had occasion to make thirty-six arrests, all of which resulted in conviction. The law governing the removal of tame stock from a forest reserve (Section 586, R. L. of H., 1925), has been invoked several times and $194.50 collected in fines. This money is paid into a special Territorial fund which is used for forestry purposes.

Forest Fires

This reserve has been very fortunate in not having had any real serious forest fires. Only once during the past ten years has it been seriously threatened. Pumps and other fire-fighting equipment are maintained by the Territory at the Hilo Nursery and are available at all times. District fire wardens always respond promptly with necessary men and equipment in case of fire and the infrequency of serious forest fires can be attributed to their prompt action, for a fire is easily controlled if reached in the early stages.

Along the lower edge of this reserve there are large areas of uluhi fern that constitute a serious fire menace. In these areas, we are attempting to reduce this hazard by first cutting lanes or paths through the fern and then planting out rapid-growing species of trees and caring for them until the trees "top" the fern. We hope that they will eventually shade out the uluhi.

By using succulent species of trees and other plants that are not inflammable, the fire hazard can be reduced. Most species of Ficus are very difficult to burn on account of the nature of their sap-wood. The use of succulents, as a means to prevent forest fires, is receiving considerable attention on the mainland and results obtained are very satisfactory.

Future Work

Tree planting has been one of our principal activities in the past and should continue to receive a considerable part of our attention in the future. New species should be tried in our different arboreta; useful species such as can be used for timber, fuel, fruit, windbreaks, etc., should be planted out in suitable areas below the actual reserve line and species of proven value should be added to our watershed area. Nursery work should continue along the same lines as heretofore in order to furnish suitable planting material for our needs.

We should continue to protect our reserve area by keeping up our fences and continuing our campaign against injurious animals.

Fire hazards should be reduced wherever possible and our fire plan revised from time to time as need requires. An effort should be made to secure a portable gasoline fire-pump and hose line for use in areas where water is available. Water is probably the most satisfactory agent with which to combat forest fires.

Rain gauge and temperature recording stations should be continued and, perhaps, new ones added. It might prove advisable for the unit to undertake the securing of stream-gauge records on some of the more important streams in this reserve.

Our knowledge of the interior of this reserve is still limited. An airplane map of the entire reserve would prove of immense value. Such a map would at once disclose all open areas regarding many of which we have no knowledge at present. It is recommended that an effort be made to secure a map of this nature.

Summary

During the past 10 years, the following work has been accomplished in the Hilo Forest Reserve:

1. The reserve has been surveyed and additions made where necessary.

2. A working organization has been perfected.

3. Trees totalling 948,042 have been planted out in, or adjacent to, this reserve.

4. Twenty-three miles of new fence have been constructed, and fences previously built have been maintained.

5. Fifty-six miles of fence have been regularly patrolled and kept in repair.

6. A total of 1,332 wild animals has been reported killed.

7. Forestry rules and laws have been strictly enforced.

8. Transportation and communication lines have been maintained and increased where needed.

9. Fire hazard has been practically eliminated in this reserve.

10. The closest possible cooperation has been maintained at all times between Unit No. 3 and the Territorial Division of Forestry.

Fig. 1. Motojiro Sadaiki, tree planter, *par excellence*, employed since 1921 by Honomu Sugar Company to plant trees. In 10 years, this man has planted out and cared for over 212,000 trees. We offer this as a record of achievement along these lines, particularly as a high percentage of these trees are alive today.

Fig. 2. Honomu Sugar Company's nursery. In addition to his tree-planting work, Motojiro Sadaiki has raised many thousands of plants in this nursery.

Fig. 3. *Trema orientalis*, 8 years old, 23 feet high, Pepeekeo Arboretum.

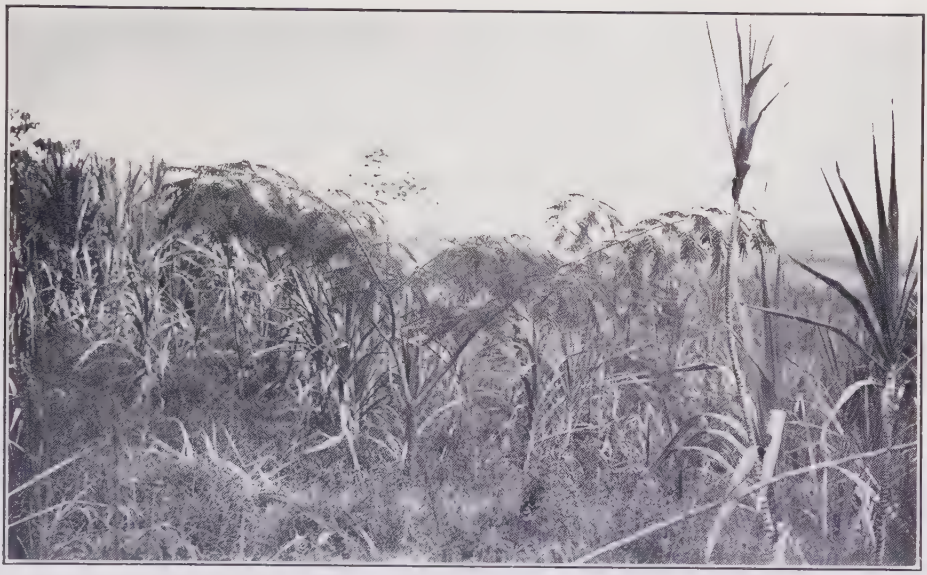


Fig. 4. *Albizzia stipulata*, 2 years old, 15 feet high. This is one of the best species of Albizzia that we have planted out on this island. Pepeekeo Aboretum.

Fig. 5. *Tristania conferta,* only 10 months old, 5 feet high. This species is doing well in our plantings from sea-level up to 5,000 feet elevation. It produces valuable timber and is one of our best trees for general planting. Pepeekeo Arboretum.

Fig. 6. *Sequoia sempervirens*, 2 years old, 4 feet high. This is the tree which produces the redwood of commerce. It is doing well in several sections of this island. Trees planted out in 1927 are now over 20 feet high. Pepeekeo Arboretum.

Fig. 7. *Angophora lanceolata*, 2 years old, 10 feet high; a relative of the eucalyptus, and is very promising. Pepeekeo Arboretum.

Fig. 8. *Podocarpus cupressina*, 8 years old, 21 feet high. Pepeekeo Arboretum.

Fig. 9. *Terminalia myriocarpa*, 8 years old, 40 feet high. This is one of the best trees that we have yet planted out. It is doing well up to 5,000 feet elevation. It is native to India, reaches a large size and produces valuable timber. Pepeekeo Aboretum.

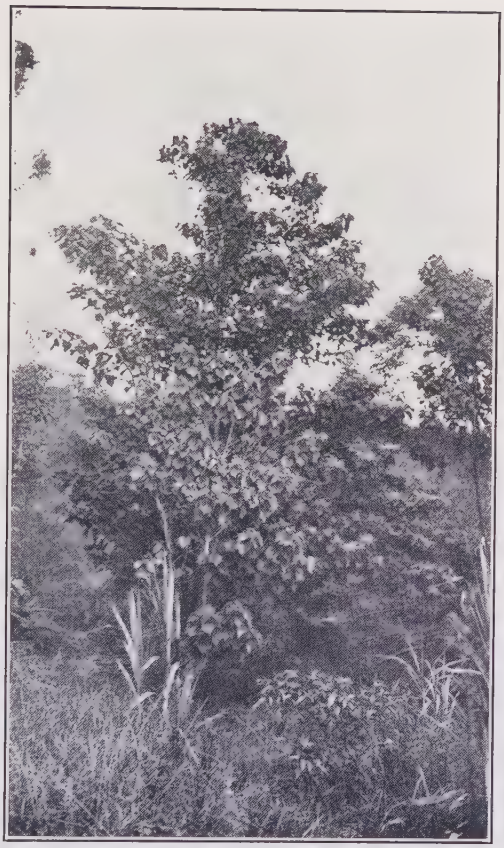


Fig. 10. *Heliocarpus americanus*, 7 years old, 30 feet high. Pepeekeo Arboretum.

Fig. 11. *Leptospermum gracilis*, 8 years old, 18 feet high. A large bush or small tree. Grows in very wet locations. Pepeekeo Arboretum.

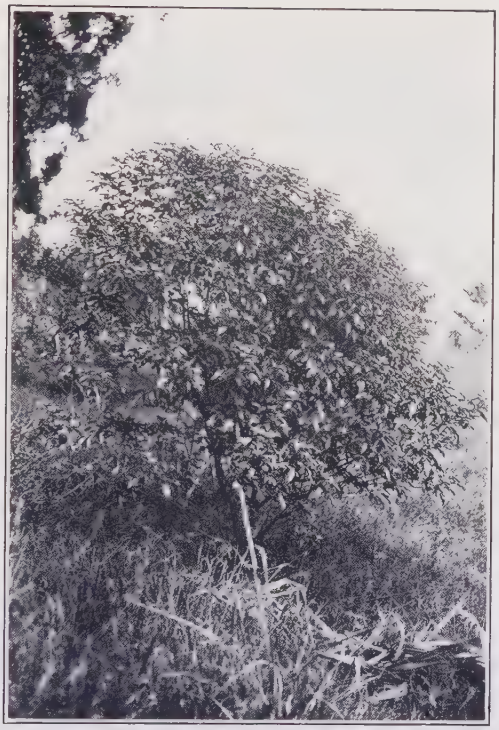


Fig. 12. *Vitex parviflora*, 8 years old, 12 feet high. A slow-growing tree, producing a very hard wood. Pepeekeo Arboretum.

Fig. 13. *Camphora officinalis*, 7 years old, 11 feet high. Pepeekeo Arboretum.

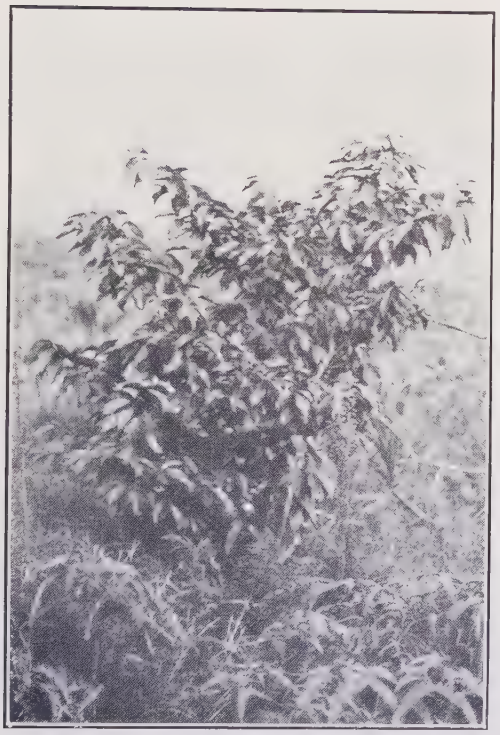


Fig. 14. *Lagerstroemia speciosa*, 7 years old, 9 feet high. Pepeekeo Arboretum.

Fig. 15. *Terminalia myriocarpa* and *Melaleuca leucadendron*, 3 years old, land of Kamaee.

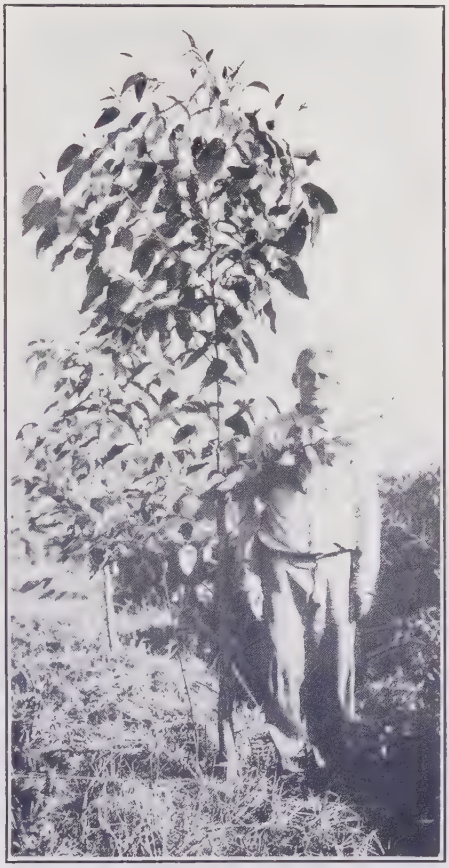


Fig. 16. *Eucalyptus robusta*, 3 years old, growing in very wet area, land of Kamaee.

Fig. 17. Showing heavy growth of uluhi fern along the lower edge of the forest reserve in the land of Kamaee. This pest has taken hold of large areas and is very difficult to plant trees in. It is a serious forest-fire menace and one of our problems is to find a means of getting rid of it and finding something more suitable to take its place.

Fig. 18. Another area of uluhi fern that has been planted up with *Eucalyptus robusta*. Our best method of control seems to be to clear paths or lanes through this fern and plant fast-growing species of trees that will eventually shade it out. The young trees in the picture can just be seen. After one more cleaning, they should be able to care for themselves.

Fig. 19. *Cryptomeria japonica* growing in uluhi fern area. This tree is too slow in rate of growth to successfully compete with this fern.

Fig. 20. *Taxodium mucronatum*, land of Hakalau-nui, 7 years old. This species is very slow in growth but eventually makes a good tree and produces good wood.

Fig. 21. *Eucalyptus rostrata*, 7 years old, land of Haka-lau-nui.

Fig. 22. *Cupressus arizonica*, 5,700 feet elevation, 6 years old, land of Laupahoehoe.

Fig. 23. Natural reproduction of *Acacia koa*. Cattle were removed from this area about 12 years ago and since then considerable native koa has come in and grown to good size. Land of Piha, elevation 5,500 feet.

Fig. 24. Nauhi Gulch Station. Here, we maintain our mauka nursery for the handling of plants suited to higher elevation. Land of Honohina, elevation 5,100 feet.

Fig. 25. Grove of mixed Eucalyptus, 8 years old, planted out by Puu Oo Ranch in mauka Makahanaloa under their lease agreement with Pepeekeo Sugar Company.

Fig. 26. *Cryptomeria japonica*, 6 years old, planted out by Puu Oo Ranch in mauka Papaikou under their lease agreement with Onomea Sugar Company.

Fig. 27. Hybrid plum, 3 years old, at Nauhi Gulch. We have planted out over sixty different varieties of fruit trees at this station. Many of them show every sign of success.

Fig. 28. *Platanus occidentalis*, 2 years old, land of Piha, 5,400 feet elevation.

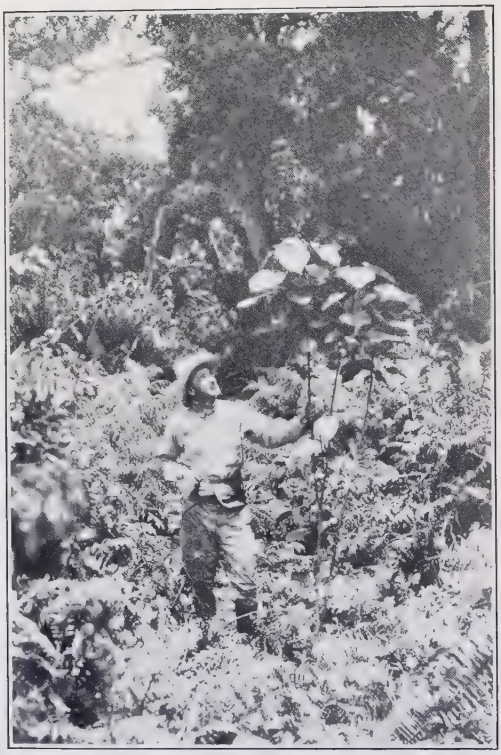


Fig. 29. *Catalpa* sp., 2 years old, land of Piha, 5,400 feet elevation.

Fig. 30. Grove of *Heliocarpus americanus*, 3 years old, land of Puueo.

Fig. 31. Grove of *Cedrela australis*, 3 years old, land of Puueo.

Fig. 32. *Jacaranda mimosaefolia,* 3 years old, land of Honomu.

Fig. 33. *Cedrela australis*, 3 years old, growing in uluhi fern, land of Puueo.

Fig. 34. *Fraxinus* sp., 3 years old. This tree has done well with us in all of our plantings from sea-level to 5,000 feet elevation. Land of Honomu.

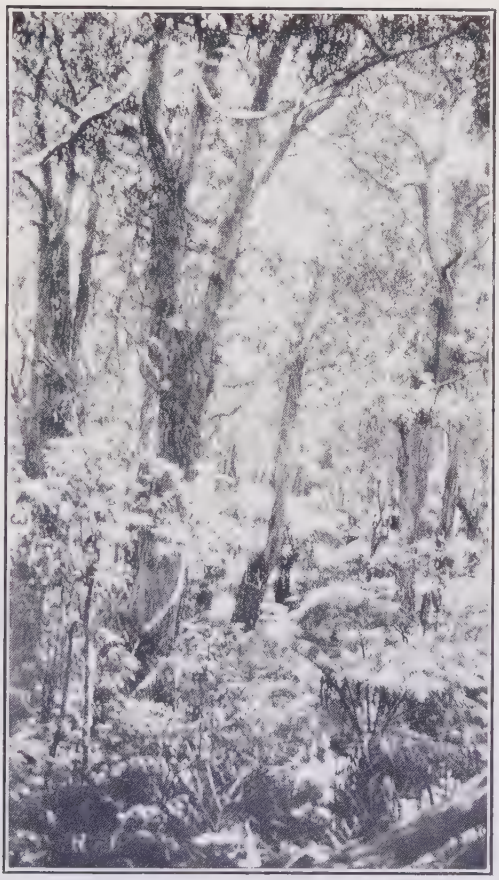


Fig. 35. Native forest growth in the land of Laupahoehoe. Some of the finest native forest can yet be found in the northern end of this reserve.

Fig. 36. Akaka Falls, highest waterfall on the Hilo coast. The area around this fall is within the reserve and is treated as a park and recreation area. It is very popular with tourists as well as with local people.

Fig. 37. *Ficus rubiginosa*, 6 years old. This is the first tree of this species to produce fertile seed on this island. The wasp has, of course, become established and we can soon expect natural seedlings. Land of Piihonua.

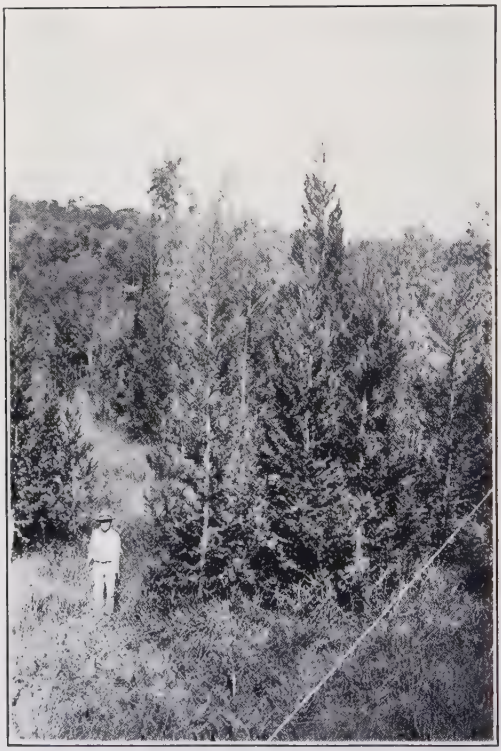


Fig. 38. *Cryptomeria japonica,* 7 years old. This tree produced a good grade of wood and does well in our very wet soils. The location where this photo was taken has an average rainfall of 233 inches per annum. Land of Piihonua.

Fig. 39. *Ficus nota,* 6 years old. This species grows best in shaded places. Land of Piihonua.

Fig. 40. Mixed planting of *Eucalyptus rostrata, Fraxinus* sp. and *Cupressus macrocarpa,* 6 years old. Land of Piihonua.

Fig. 41. *Ficus nota in fruit.* The wasp for this species has not yet been introduced from the Philippines. Land of Piihonua.

Fig. 42. *Monstera deliciosa*, 6 years old. A number of these aroids have become established along the gulch sides in this section. Land of Piihonua.

Fig. 43. Indian fire pumps in use. These pumps are most useful for "mopping up" work and a number of them are kept on hand at the Hilo Nursery and ready for use at all times, together with other fire-fighting equipment. Every plantation would, undoubtedly, find a number of these pumps a good investment.

Fig. 44. *Eugenia cumingii,* 7 years old, in foreground. The trees in the background are 20-year-old *Eucalyptus robusta.* For very wet locations, this tree does as well as any we have tried. Pepeekeo Arboretum.

Plantation Interval Tests

By H. R. Shaw

The interval test, a type of irrigation field experiment, has proved of direct value to many plantations. These studies on the relation of time of application to cane yield have contributed to a knowledge of plant and water relations and of the most desirable irrigation policies. The chief value of the interval test has been to provide a "short cut" which, otherwise, might require years of experience by the "trial and error" method.

A completely reliable method of determining the proper distribution of irrigation waters to plantation fields is an exceedingly difficult problem to solve. Soil variation, the distribution and movement of soil moisture, and the growth of the cane plant as related to the involved and ungovernable factors of sunshine, light, and natural precipitation form variables whose effect is even more pronounced in irrigation experiments than in many other types of investigation.

In 1923, the agricultural department of the Ewa Plantation Company developed the interval test in an effort to obtain results which might be applied directly and profitably to field conditions. The interval between irrigations to adjacent plots, rather than the quantity of water, was varied, and the assumption tacitly made that the irrigator employs essentially the same amount of water during the course of an irrigation.

"Under one's own local conditions, the chief way to control irrigation is through regulation of the interval," W. P. Alexander, former agriculturist of the Ewa Plantation Company, points out. "One can't tell a water luna to apply 5 acre-inches of water per month, but one can issue orders to irrigate the cane every 15 days on the assumption that each irrigation will supply 2.5 acre-inches. It is for this reason, if none other, that the interval test offers a practical method of finding out the proper use of water and of being able to apply these data in a practical manner."

The area irrigated by one level ditch was taken as the plot unit in the interval test. The plot area was necessarily large, seldom being less than one acre, and frequently ranging as high as 4 acres in size.

In each experiment, three irrigation treatments were usually compared. By a *maximum* treatment, the cane received frequent irrigations at a rate more rapid than was popularly considered to be practical with the irrigation methods and available water supply in use; a *normal* treatment supplied the cane with adequate irrigations as based on the best conditions, from the standpoint of water and labor supply, that the plantation could offer; and by a *minimum* treatment, irrigations were made as seldom as possible without allowing the cane to die. A fourth treatment, plantation practice or check, by which irrigation water was applied at the same interval as that to the surrounding field, was occasionally added.

Due to the size of the plots, three replications of each treatment arranged in series or in "checkerboard" fashion were all that could be maintained profitably.

Thus, each test consisted of from 9 to 12 level-ditch plots usually covering a total area of from 9 to 40 acres.

The interval between irrigations to each plot series was determined somewhat arbitrarily by past experience and collateral investigation. No particular effort was made to control the amount of water applied during each irrigation as the difficulties of such refinement in field experimentation with sugar cane are great unless a disproportionate degree of supervision is given. In a majority of the experiments, water to each plot was measured at the entrance to the level ditch by means of a submerged orifice installation supplemented by a portable mechanical meter. Rectangular weirs and Parshall flumes were used for the measurement of water to the experiments of the Pioneer Mill Company.

The plan of the interval test seemed to answer many of the requirements of a comparatively simple and direct means of irrigation investigations. Level-ditch plots large enough to permit a normal and consistent supply of water, reduced the lateral movement of water between plots to a minimum, and provided natural boundaries for the harvesters. The simplicity of the method appeared to require little more than routine attention and supervision for satisfactory results, and there seemed every indication that the results might be of direct and profitable value to the plantation.

Following the inauguration and initial success of the interval test at Ewa Plantation Company, similar investigations were installed on other plantations with varying success. Perhaps the largest and most ambitious of these projects was that sponsored by the American Factors, Ltd., on three of its Kauai plantations, Koloa Sugar Company, Lihue Plantation Company, and Makee Sugar Company. There, however, difficulties which were not apparent under the relatively constant water supply and equable climate of Ewa, confronted the investigators, and the conduct and interpretation of the tests was a much harder task.

The irrigation supply of the three plantations is almost entirely dependent upon mountain rainfall and, with the exception of the Koloa plantation, which has a considerable reservoir reserve, the supply may fluctuate greatly throughout the year. Rainfall, always a difficult factor to evaluate, is comparatively heavy on this portion of Kauai, and the steeper slope of the land necessitates even greater care in the installation and operation of water-measuring devices than is the case on the level Ewa terrain. During periods of drought, with which the Kauai plantations are frequently afflicted, it has often been impossible to maintain even the minimum irrigation treatment. The prevalence of rat damage and of eye spot and other pathological diseases added further complications to the tests.

Disadvantages of the Interval Test

Although large experimental plots may have an advantage in the smooth-running routine of a plantation, they frequently prove disastrous in the conduct and subsequent interpretation of an experiment. Few localities in the Hawaiian Islands have so uniform a soil that, in a large experimental area, the error due to soil variation will not exert a profound influence. The limited number of replications prevent statistical scrutiny of the results, and serve mainly to indicate

major deviations between plots of the same treatment. The arithmetical average of the results from the three plots of a series frequently deviates so greatly from any one of the individuals that its true value is debatable.

The nature of the physical and moisture-holding properties of the soil undoubtedly has a major influence on the amount and time of irrigation applications. Many plantations using interval tests have attempted roughly to classify certain areas of their estates according to soil type as determined by structure or as affected by prevailing weather conditions, and arbitrarily to assign the interval between irrigations to each plot based on the results of experience in that area. Such classifications, although probably necessary as a first departure, do not take into account the gradation of one soil type into another, the variation in moisture-holding properties of the soil, nor the local variation in climate over comparatively small and restricted areas.

One of the greatest dangers connected with the conduct of interval tests is the fallacy that a fixed interval between irrigations may be maintained throughout a crop without regard to the effect of seasonal variation on water consumption and cane growth. Although many plantations have recognized this factor and have attempted, by the use of detailed growth measurements in each plot, to evaluate the effect of seasonal variation on the growth of sugar cane, the yearly differences in temperature, rainfall, hours of sunshine, and similar factors may be great enough to limit the value of the results. This danger has sometimes been overlooked or neglected, and the same interval maintained throughout the crop.

"I feel that the seasonal effect of irrigation intervals should be further investigated, particularly in cane that is above waist high," writes K. B. Tester, assistant manager of Pioneer Mill Company. "In young cane one has to do weeding and the oftener he gets around with irrigations, the cleaner the field. In larger cane, however, the weeding question does not come in."

Closely allied with the problem of seasonal variation on irrigation intervals is that influenced by the age of the cane. Certainly it is logical to expect that as the foliar growth and the root system of the plant develop, the draft of moisture from the soil will increase manifold; yet, with few exceptions, this factor has not been considered in most interval tests. The age of cane also exerts an influence on the surface distribution of water. As the cane approaches maturity and as obstructions to the stream caused by recumbent cane, leaves, and trash increase, the assumption that essentially the same amount of water is used in each irrigation may, and probably does, vary from the truth. Hence, if we may consider that the quantity of water used increases with the age of cane, the two variables of time and quantity enter the experiment at each successive irrigation.

The type of crop may also exert an influence on the irrigation interval. Young plant cane requires frequent irrigations to provide rapid germination and growth; on the other hand, ratoon cane is apparently able to thrive for some time without irrigation provided that water is applied immediately after harvest. As cane is successively ratooned, the physical condition of the field often becomes poor, furrows and ditches are silted until their capacities are greatly reduced, watercourses are eroded, and the surface soil is packed and compressed. Thus, it

would seem logical that the interval between irrigations should be more frequent than that to plant or young ratoon fields, and that the results of tests on old ratoons might be affected significantly by surface conditions.

"It seems that a plant or young ratoon crop gets the water where it is wanted," Mr. Tester comments. "Often the physical condition of an older ratoon makes the use of water wasteful. Although water measurements generally show that old ratoons use more water, a large amount of this is probably lost. At Pioneer Mill Company, the plant fields take much less water per round than do the ratoons. I feel that the physical condition of the field is about as large a factor as anything in determining the amount of water applied."

An intangible factor, but one important in the successful conduct of an interval test, is the attitude of the labor toward it. Not infrequenly the irrigator considers that a comparison of "plantation practice" with other irrigation treatments is an implied reflection on his standard of work. The reaction often has been to favor plots under such practice over those receiving other treatments and to justify his methods by special care and attention.

Results of Typical Interval Tests

The application of experimental results to the irrigation routine of Ewa Plantation Company has been thoroughly discussed in previous papers by members of the plantation staff. Interval tests at Ewa have led to the conclusion that the first irrigation to ratoon cane should be applied immediately after harvest, that frequent irrigations are not needed for very young ratoons, and that cane between the ages of 3 to 11 months exhibits the greatest response to optimum irrigation and fertilization. It has also been established at Ewa that cane over 11 months of age does not respond to frequent irrigations, and that the interval should be gradually extended in the "pre-maturity" stage—from 14 months of age to within 40 to 80 days of harvest.

Through the courtesy of the Koloa Sugar Company, Lihue Plantation Company, and Pioneer Mill Company a summary of the results from typical interval tests harvested for the crops of 1927 to 1931 has been prepared. The data are presented in terms of acre-inches of water applied for the crop and in average yields of tons cane and tons sugar per acre. Unless otherwise noted, H 109 is the cane variety grown in each test, and water has been applied by the standard contour system of irrigation.

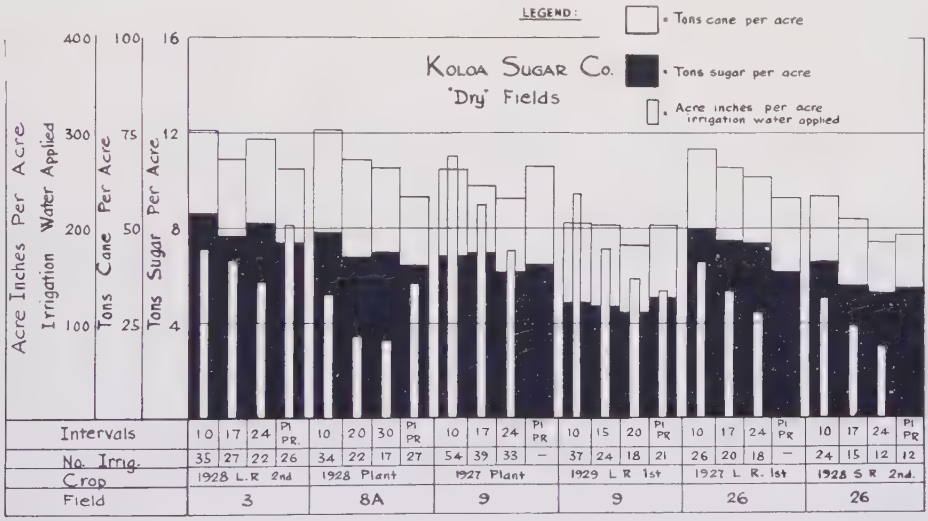
The majority of the interval tests on these plantations point decisively toward the beneficial results accruing from frequent applications of water. The frequency of irrigations indicated by the results of these experiments was not always obtainable under the methods of irrigation and the water and labor supply then existing. The results of interval tests on the plantation of the Koloa Sugar Company are directly responsible for the development and extension of the "Koloa System" of irrigation by which it has been possible to irrigate the same area with more than double the previous frequency without an increase of labor or water supply. J. T. Moir, Jr., manager of Koloa Sugar Company, writes, "Our whole present practice of irrigation is predicated on the general results of the tests run

here. We were sufficiently convinced that a faster, lighter irrigation would be productive of increased yields of cane and sugar. Our recent results seem to have justified our conclusions." The increased frequency between irrigation applications is also an outstanding feature of the border method of irrigation which has been developed and extended in Hawaii since 1926.

The interval test may prove of much value by indicating the relationship between frequency of irrigations and yield in areas previously not under cultivation or in which a definite and concrete irrigation policy founded by long experience has not been established. Tests on many plantations have demonstrated that regularly planned and scheduled intervals between irrigations result in increased cane yields. Evidence from these and other experiments indicates that a distinct depression of growth may result from over-irrigation, particularly on wet, poorly drained soils.

Case I—Koloa Sugar Company—"Dry" Fields

The series of interval tests represented in Fig. 1 were conducted on plantation fields at a low elevation and which receive a relatively small annual rainfall.



Intervals	10	17	24	Pl PR.	10	20	30	Pl PR	10	17	24	Pl PR	10	15	20	Pl PR	10	17	24	Pl PR	10	17	24	Pl PR
No. Irrig.	35	27	22	26	34	22	17	27	54	39	33	–	37	24	18	21	26	20	18	–	24	15	12	12
Crop	1928 L.R 2nd				1928 Plant				1927 Plant				1929 L R 1st				1927 L R. 1st				1928 S R 2nd.			
Field	3				8A				9				9				26				26			

Fig. 1

A casual inspection of the data as presented in Fig. 1 intimates a proportional relationship between amount of water applied and final yields of cane and sugar. The descending order of cane yield and irrigation water for each treatment is especially marked in Fields 8-A and 26 for both the 1927 and 1928 crops. Differences in cane ratios cause the proportion between water applied and yield in tons sugar per acre to be less apparent, but in at least four of the cases, increased yields of sugar resulted from the maximum treatment. The fact that the two factors of time and of quantity of irrigation applications are involved leads to the question as to whether the greater amounts of water or the greater rapidity of successive applications resulted in the increased yields. In view of our present

knowledge of plant and water relations, it seems probable that the frequency of applications rather than the total amount of water applied was the factor instrumental in the increased yields of the first treatment. Comparison of results, especially on the basis of tons sugar, between the normal and minimum treatments of the experiments in this series, is difficult, and the differences are apparently insignificant. The plantation practice showed a decrease in yield with a greater consumption of water over all other treatments in Fields 3 and 8-A of the 1928 crop and in Field 26 of the 1927 crop, a slight increase in cane yield over all other treatments in Field 9 of the 1927 crop, and no significant difference between treatments in Field 9 of the 1929 crop.

In many of the cases reported in this paper a specific irrigation treatment apparently causes a commanding difference in tons cane per acre over other treatments, but lower juice quality results in no significant difference in the yields as based on tons sugar per acre. Mr. Alexander comments on this factor as follows: "I am impressed with the depressing effect of the extra water on the sucrose content. This might merit a special study of its own. In so many of these tests the cane yield due to the frequent waterings was counteracted by a higher quality ratio. This brings up the question of how the cane was irrigated in the last stages of the crop. With less water then, the results might have been different. It was found at Ewa that an analysis of the quality ratio was not enough; the Brix and purity were bigger factors to study."

Case II—Koloa Sugar Company—"Medium" Fields

The series of experiments represented in Fig. 2 are situated in the central belt of the plantation at an elevation of 100-300 feet, and receive a normal rainfall of 60 inches.

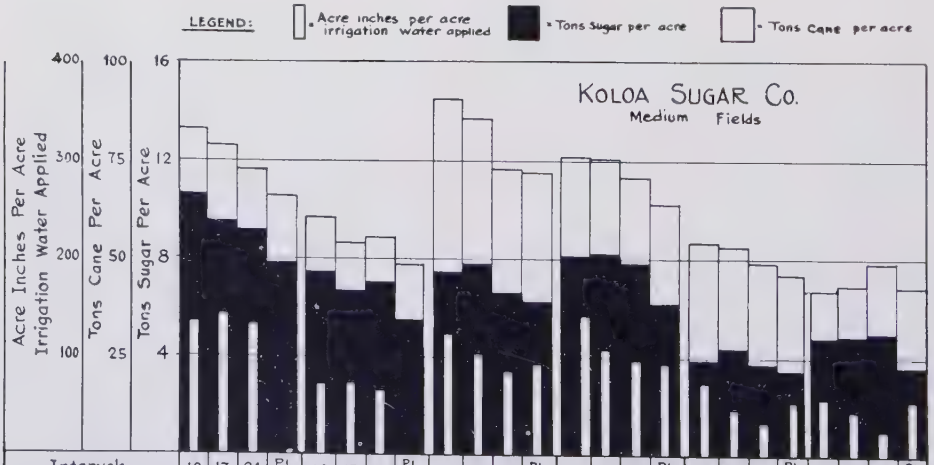

LEGEND:
= Acre inches per acre irrigation water applied
= Tons Sugar per acre
= Tons Cane per acre
KOLOA SUGAR CO.
Medium Fields
Acre Inches Per Acre Irrigation Water Applied
Tons Cane Per Acre
Tons Sugar Per Acre
400
300
200
100
100
75
50
25
16
12
8
4
Intervals 10 17 24 Pl PR. | 10 17 24 Pl PR | 10 17 24 Pl PR | 10 17 24 Pl PR. | 10 17 24 Pl PR. | 10 17 24 Pl PR.
No. Irrig. 34 27 23 22 | 25 15 11 17 | 38 27 23 19 | 38 27 23 19 | 23 15 10 13 | 23 15 10 13
Crop 1927 Plant | 1928 S.R. 1st | 1927 Plant | 1927 Plant | 1928 S R 1st | 1928 S.R. 1st.
Variety H109 | H109 | Y. T. | H 109 | Y.T | H 109
Field 24 | 24 | 35 | 35 | 35 | 35

Fig. 2

The beneficial effect of frequent irrigation applications on the yield of cane and sugar seems indicated by the results from Field 24, 1927 and 1928 crops. No significant differences in cane or sugar yields between the maximum and normal treatments is indicated by the results of the experiment in Field 35, planted to H 109 and to Yellow Tip varieties for the crops of 1927 and 1928, although each of the three treatments resulted in a higher yield than that of the plantation practice. It seems apparent that, although soil and climatic conditions would seem to be more conducive to longer intervals between irrigation than those maintained in the "dry" fields, increased yields resulted from increasing the frequency of irrigations over the usual practice. No varietal differences between H 109 and Yellow Tip on the desirable interval between irrigations is apparent from the data. It may follow that the soil type rather than the variety of cane is the governing influence on the amount and frequency of irrigation applications under normal conditions of climate and growth.

Case III—Koloa Sugar Company—"Wet" Fields

Experiments in the series reported in Fig. 3 are, with the exception of Field 7, which is classed as a "medium" soil, from fields of heavy soil with high moisture-holding characteristics in the poorly drained Mahaulepu district of the plantation.

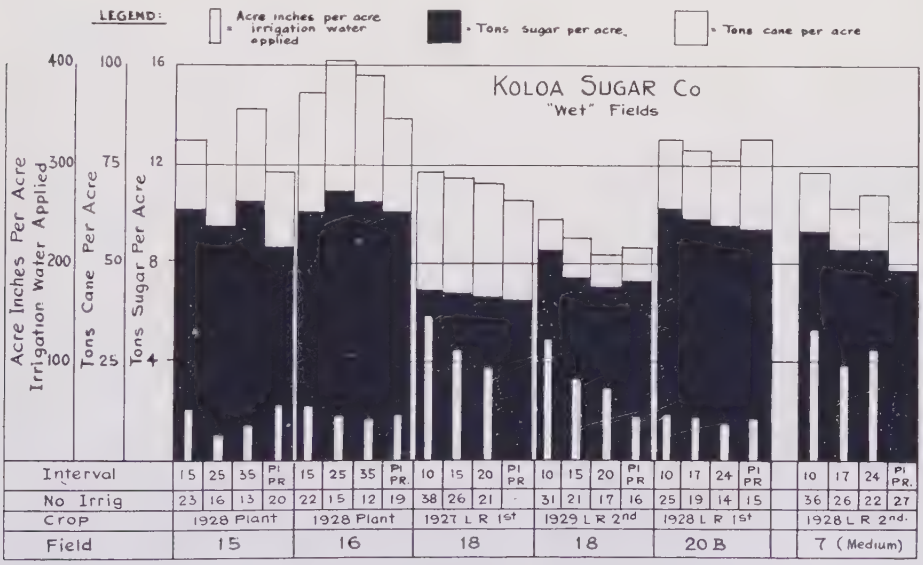

LEGEND:
Acre inches per acre = irrigation water applied
= Tons sugar per acre.
= Tons cane per acre
KOLOA SUGAR CO
"Wet" Fields
Acre Inches Per Acre Irrigation Water Applied
Tons Cane Per Acre
Tons Sugar Per Acre
400 100 16
300 75 12
200 50 8
100 25 4
Interval 15 25 35 PI PR 15 25 35 PI PR 10 15 20 PI PR 10 15 20 PI PR 10 17 24 PI PR 10 17 24 PI PR.
No Irrig 23 16 13 20 22 15 12 19 38 26 21 - 31 21 17 16 25 19 14 15 36 26 22 27
Crop 1928 Plant 1928 Plant 1927 L R 1st 1929 L R 2nd 1928 L R 1st 1928 L R 2nd.
Field 15 16 18 18 20 B 7 (Medium)

Fig. 3

The results from Field 15 and Field 16 of the 1928 crop appear to point to longer intervals between irrigations for soil of this nature. In the former case, an interval of 35 days gave the highest yield, while in Field 16 the 25-day interval led. Although the plots under the plantation practice received more irrigations than any other treatment except the maximum, yields of both cane and sugar were depressed. The possibility of over-irrigating heavy soils with poor drainage is indicated.

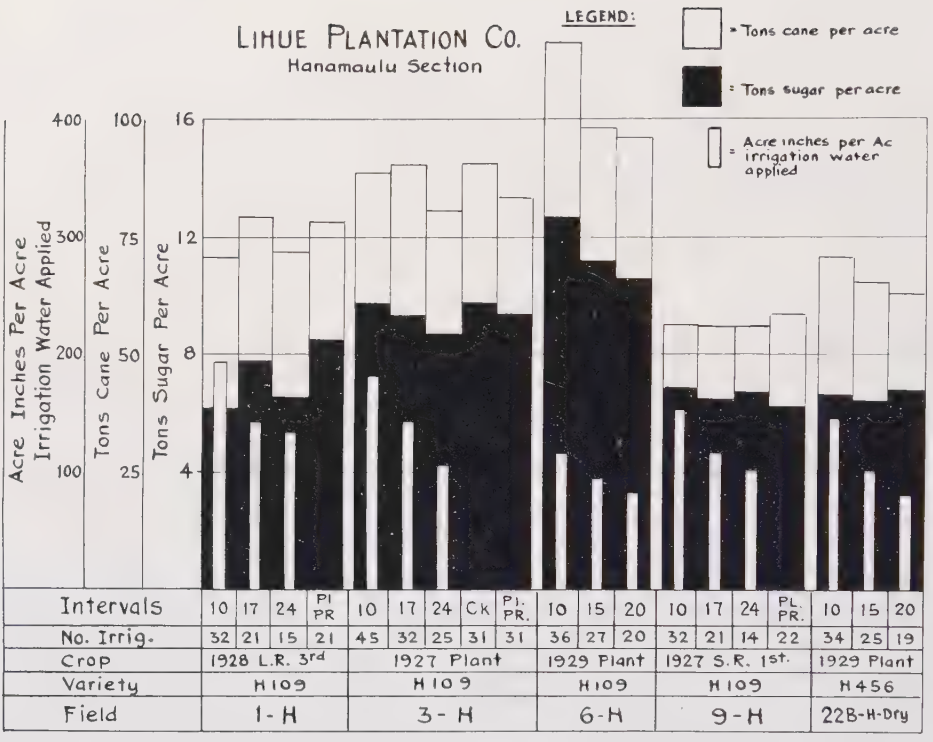

LIHUE PLANTATION CO.
Hanamaulu Section
LEGEND:
= Tons cane per acre
= Tons sugar per acre
= Acre inches per Ac irrigation water applied
Acre Inches Per Acre Irrigation Water Applied
Tons Cane Per Acre
Tons Sugar Per Acre
400
300
200
100
100
75
50
25
16
12
8
4
Intervals 10 17 24 Pl PR | 10 17 24 Ck Pl. PR. | 10 15 20 | 10 17 24 PL. PR. | 10 15 20
No. Irrig. 32 21 15 21 | 45 32 25 31 31 | 36 27 20 | 32 21 14 22 | 34 25 19
Crop 1928 L.R. 3rd | 1927 Plant | 1929 Plant | 1927 S.R. 1st. | 1929 Plant
Variety H109 | H109 | H109 | H109 | H456
Field 1-H | 3-H | 6-H | 9-H | 22B-H-Dry

Fig. 4

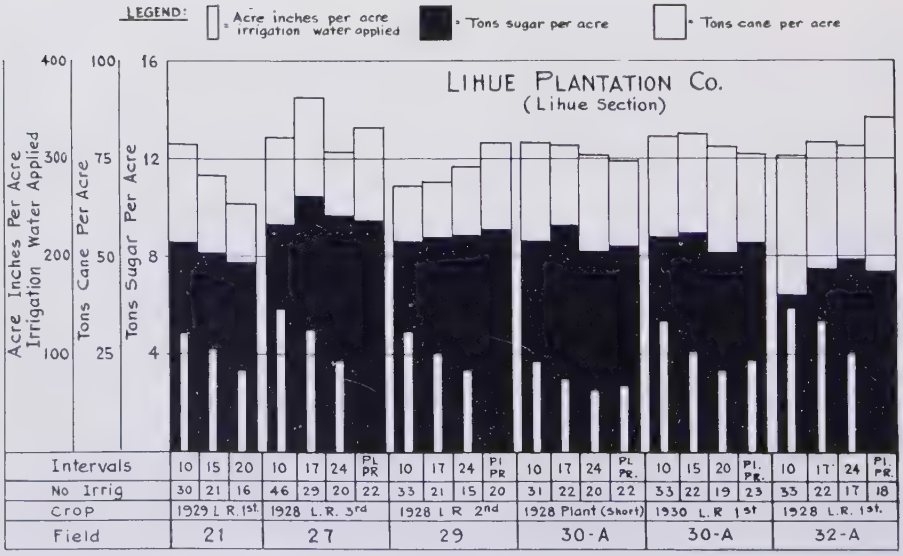

LEGEND:
= Acre inches per acre irrigation water applied
= Tons sugar per acre
= Tons cane per acre
LIHUE PLANTATION CO.
(Lihue Section)
Acre Inches Per Acre Irrigation Water Applied
Tons Cane Per Acre
Tons Sugar Per Acre
400
300
200
100
100
75
50
25
16
12
8
4
Intervals 10 15 20 | 10 17 24 PL PR | 10 17 24 PL PR | 10 17 24 PL PR. | 10 15 20 PL. PR. | 10 17 24 PL PR
No Irrig 30 21 16 | 46 29 20 22 | 33 21 15 20 | 31 22 20 22 | 33 22 19 23 | 33 22 17 18
Crop 1929 L R 1st. | 1928 L.R. 3rd | 1928 L R 2nd | 1928 Plant (Short) | 1930 L.R 1st | 1928 L.R. 1st.
Field 21 | 27 | 29 | 30-A | 30-A | 32-A

Fig. 5

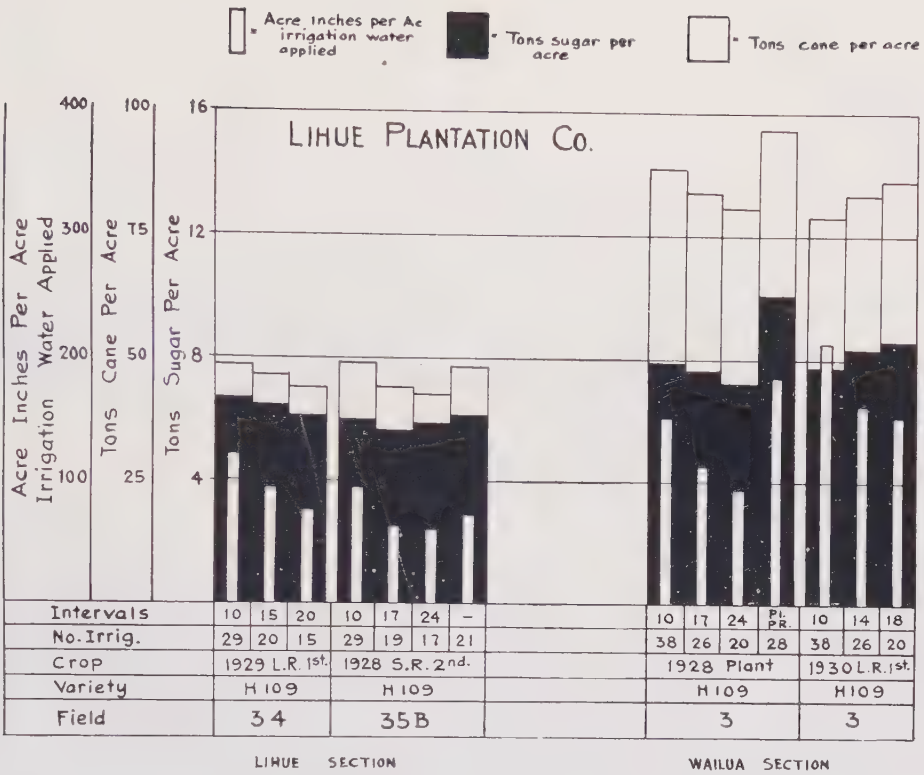

Acre Inches per Ac irrigation water applied
Tons sugar per acre
Tons cane per acre
LIHUE PLANTATION CO.
Acre Inches Per Acre Irrigation Water Applied
Tons Cane Per Acre
Tons Sugar Per Acre
400
300
200
100
100
75
50
25
16
12
8
4
Intervals 10 15 20 10 17 24 – 10 17 24 Pl. PR. 10 14 18
No. Irrig. 29 20 15 29 19 17 21 38 26 20 28 38 26 20
Crop 1929 L.R. 1st. 1928 S.R. 2nd. 1928 Plant 1930 L.R. 1st.
Variety H 109 H 109 H 109 H 109
Field 34 35B 3 3
LIHUE SECTION
WAILUA SECTION

Fig. 6

Although the differences are not as marked as on the dry or medium soils, the remaining experiments of this series seem to show the trend noted previously of a proportional relationship between frequency of irrigation applications and resulting yield. The maximum treatment of 10-day intervals between irrigations resulted in the highest yield of cane and sugar in all cases.

Case IV—Lihue Plantation Company—Hanamaulu Section

The interval tests conducted by Lihue Plantation Company do not, in general, lend themselves to the casual inspection and more apparent interpretation which mark the experiments of the Koloa Sugar Company. Several complicating factors appear to add difficulty to the operation of plantation tests such as those reported here. The plantation possesses diverse and variable soil types which make experimentation in large plots with few replications hazardous. "Blank" tests in which a series of level ditches under uniform treatment of fertilization and irrigation were harvested as individual plots showed great deviations in yield, and indicated marked soil diversity. Many of the experimental fields were ravaged by eye spot and other pathological disturbances. Moreover, it is possibly significant to note that the only experiments which demonstrated clear-cut differences in yields between treatments were those operated independently without comparison with previous practice.

With the exceptions of Field 6-H and Field 22-B-H, which indicate increased yields with more frequent applications of water, no opinion on the most suitable policy of irrigation can be gained from the results of these experiments.

Case V—Lihue Plantation Company—Lihue Section

The majority of the experiments in this series of interval tests likewise fail to demonstrate results which would warrant serious consideration of a change in the plantation irrigation policy.

The results from the experiment in Field 21, with differences of 0.5 ton of sugar between each treatment, are rather clear-cut indications of higher yields from more frequent intervals between irrigations. The 17-day interval in Field 27 established an increase of nearly one ton of sugar over its nearest competitor. The results of the remaining experiments of the series are inconsistent or inconclusive. In nearly every case, the yield from plots under plantation practice was equal to or better than that of other treatments in the series, which might lead one to believe that the usual practice was close to the optimum under the conditions of the experiment.

Case VI—Lihue Plantation Company—Lihue and Wailua Sections

Three of the four experiments in this series point to greater yields from increased frequency of irrigation applications. The proportional trend of yield and interval is apparent in all experiments save that of Field 3 in the 1930 crop. In this case it should be noted that the difference between intervals has been reduced to four days. In general, it appears difficult to determine appreciable differences in results when the interval treatments are spaced too closely together. Differences in interval treatments of about 7 days seem the least which may be expected to reveal definite differences in the results. The minimum interval, 18 days, in Field 3 of the 1930 crop is equivalent to the normal treatment to the same field for the preceding crop.

The usual ability of the plantation practice to equal or better the yields under any of the other treatments is maintained in the experiments of this series.

Case VII—Pioneer Mill Company

The experimental fields reported in Fig. 7 represent a considerable range of soil types and climatic conditions. Field 31 is a red loam soil in the Honokawai Section at 400 feet elevation. The climate is cooler and the rainfall greater than that in the central portion of the plantation. Field MC-9 is an extremely rocky field in the Launipoko Section at an elevation of 250 feet. Field O-10 has a sandy soil, heavily infested with nutgrass, near sea level in the Lahaina Section. The climate is hot and the rainfall relatively slight.

The results of the experiment in Field 31 plainly indicate that increased yields may be expected from more frequent irrigations. This experiment is considered by the plantation staff to be an outstanding example of the value of interval tests on the plantation. Prior to the completion of the experiment it had been felt that,

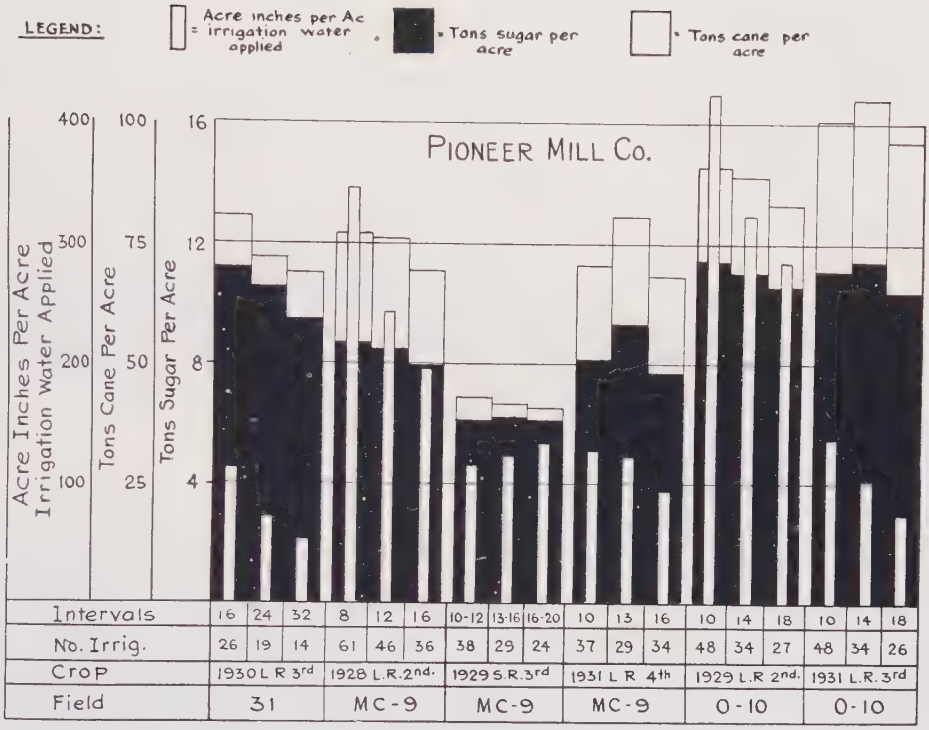

LEGEND:
Acre inches per Ac = irrigation water applied
= Tons sugar per acre
= Tons cane per acre
PIONEER MILL CO.
Acre Inches Per Acre Irrigation Water Applied
Tons Cane Per Acre
Tons Sugar Per Acre
400
300
200
100
100
75
50
25
16
12
8
4
Intervals 16 24 32 8 12 16 10-12 13-16 16-20 10 13 16 10 14 18 10 14 18
No. Irrig. 26 19 14 61 46 36 38 29 24 37 29 34 48 34 27 48 34 26
Crop 1930 L R 3rd 1928 L.R. 2nd. 1929 S.R. 3rd 1931 L R 4th 1929 L.R 2nd. 1931 L.R. 3rd
Field 31 MC-9 MC-9 MC-9 O-10 O-10

Fig. 7

due to the higher elevation and cooler climate, intervals between irrigations in the Honokawai Section could be extended far beyond those of fields in the warmer portion of the plantation. The results of the experiment indicated the necessity of a change in policy toward more frequent irrigations.

C. E. S. Burns, manager of Pioneer Mill Company, states: "We at Pioneer feel that the interval tests which we have conducted are of considerable value. Formerly we thought 30-day water was fast enough in the Honokawai Section, and during the dry spells we were lucky if it did not go twice that long. The interval tests in Field 31 show plainly the results of shorter irrigation intervals. We now try to keep the normal interval around 15 days. On the warmer sections of the plantation, most of Wahikuli and Lahaina, it has always been the practice to get around with the water every 10 to 12 days. Tests show this to be about right."

Results from the other experiments in this series are less conclusive due, perhaps, to the slight differences between intervals in the various treatments. Field MC-9 in the 1928 crop showed little difference in results between the maximum and normal intervals, but a considerable decrease resulted in plots under the minimum treatment. A flexible schedule with but slight variation between treatments was attempted in the 1929 crop, but little significance in the results was established. The experiment continued in the 1931 crop with interval differences of three days between treatments, and showed the highest yield from the 13-day interval. The

results of the experiment after three successive crops show a decided trend toward frequent irrigations at intervals of 10 to 13 days.

The sandy O-10 field for the 1929 crop indicated slightly higher yields under the maximum frequency of irrigation, but at the price of a tremendous consumption of water. In 1931, the same experiment showed a slight gain from the 14-day treatment over the other plots. Again, the little variation between intervals to the different plots tended to mask decisive differences between treatments or between the results of successive crops.

One of the practical advantages of the interval test is illustrated in the results of the experiments in Fields MC-9 and O-10. For the first crop in which the test was conducted, tremendous amounts of irrigation water, which for one treatment totalled 423.60 acre-inches per acre for the crop, were applied. In the succeeding crop, the management was able to reduce these applications from one-half to two-thirds of the previous total.

Case VIII—Pioneer Mill Company

The experiments of this series are from three fields repeated for two successive crops. The results indicate the advisability of repeating interval tests for two or more crops if confidence is to be placed in the conclusions drawn from the experiment. Field I-5 is a rocky, red-loam soil at an elevation of 75 feet. Field C-6 is a red-loam soil at 250 feet elevation in the Puukolii Section of the plantation. Field B-4, also in the Puukolii Section, is a red-loam at an elevation of 500 feet.

The figures reported in Fig. 8 show that in Field I-5, 1928 crop, the results were indecisive with a gain of less than 0.2 of a ton of sugar in favor of the

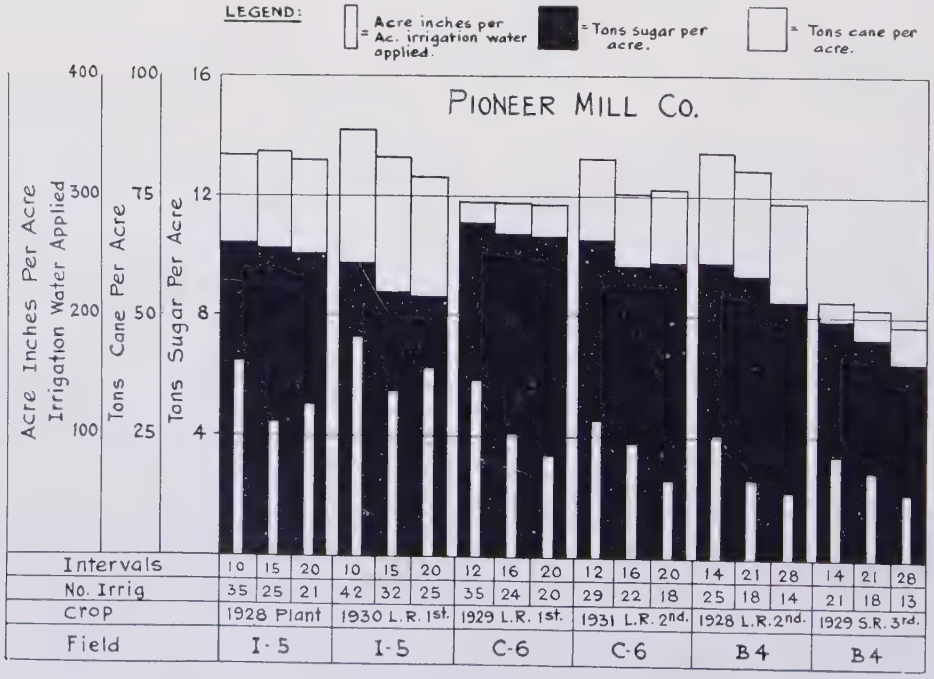

LEGEND:
= Acre inches per Ac. irrigation water applied.
= Tons sugar per acre.
= Tons cane per acre.
PIONEER MILL CO.
Acre Inches Per Acre Irrigation Water Applied
Tons Cane Per Acre
Tons Sugar Per Acre
400
300
200
100
100
75
50
25
16
12
8
4
Intervals 10 15 20 | 10 15 20 | 12 16 20 | 12 16 20 | 14 21 28 | 14 21 28
No. Irrig 35 25 21 | 42 32 25 | 35 24 20 | 29 22 18 | 25 18 14 | 21 18 13
Crop 1928 Plant | 1930 L.R. 1st. | 1929 L.R. 1st. | 1931 L.R. 2nd. | 1928 L.R. 2nd. | 1929 S.R. 3rd.
Field I-5 | I-5 | C-6 | C-6 | B4 | B4

Fig. 8

maximum interval. In the 1930 crop of the same experiment, however, a clear-cut verdict in favor of frequent applications of irrigation water seems apparent.

Experiment C-6 of the 1929 crop likewise failed to demonstrate significant differences between treatments although the trend appears to favor the closer interval between applications. On repetition of the experiment in the 1931 crop, the gain in yield of the plots under the maximum interval over the normal and minimum treatments appears conclusive, although no significant differences appear between the last two treatments.

The test in Field B-4 demonstrated proportional decreases in yield with longer intervals between irrigations for both the 1928 and 1929 crops. In general, the plantation seems justified in concluding that increased yields can be gained, especially in the Puukolii Section, from increased frequency of irrigation applications.

Acknowledgment

The courtesy of the plantations concerned in making available the data from typical interval tests is sincerely appreciated. Thanks for their interest and comments on the manuscript are due particularly to C. E. S. Burns, manager; K. B. Tester, assistant manager; and H. J. W. Taylor, agriculturist, of Pioneer Mill Company; to R. D. Moler, manager, and P. G. Rice, in charge of irrigation investigations, Lihue Plantation Company; and to J. T. Moir, Jr., manager, and E. T. Gillan, civil engineer, of Koloa Sugar Company. Mr. Gillan is responsible for the form of concise graphic presentation used in the text.

The writer is also indebted to the following for reviewing the manuscript and for their comments and additions to the material:

George F. Renton and J. B. Menardi, Jr., of Ewa Plantation Company; R. M. Allen, former assistant manager of Pioneer Mill Company; W. P. Alexander, former head of the agricultural department, Ewa Plantation Company; G. H. W. Barnhart, of American Factors, Ltd., and Norman King, former agriculturist of Pioneer Mill Company.

Response of Cane Plants to Soil Sterilization

By J. N. P. Webster

During 1931, some studies were made on the growth of cane seedlings in flats containing various mixtures of soil, with compost, mudpress, black sand, bagasse and beet compost, in sterilized and unsterilized condition. It was noted that in practically every case seedlings growing in mixtures which had been sterilized made better growth than those planted in unsterilized mixtures. Thus it would seem that the sterilization of the soil resulted in some beneficial effect.

To determine if this influence would be shown in ordinary Makiki soil planted to different varieties of cane it was decided to install a small experiment using large tubs.

Experiment No. 1

A sufficient amount of soil to a depth of about eight inches was removed from Field 6 of the Makiki plots and thoroughly composited. One part was then immediately placed in tubs in an unsterilized condition. A second part was placed in bags and sterilized with steam in the same manner as soil used in seedling work, and then put into the tubs. The third part was sterilized by formaldehyde. A large tarpaulin was spread on a floor and as the soil was added in thin layers, making a pile, a solution of formaldehyde was sprinkled over each layer. Ten gallons of a solution of 40 per cent formaldehyde made up in the proportion of one gallon to 50 gallons of water was used. The sprinkled pile was then covered with the remaining area of the tarpaulin and allowed to remain for two days. At the end of this time the covering was removed, the pile spread out over the tarpaulin in a thin layer and mixed once every day for a week before the soil was placed in the tubs.

A total of 27 galvanized tubs each holding approximately 140 pounds of soil were used. One set of each treatment was planted with four seed pieces of each of the following varieties:

H 109
Yellow Caledonia
D 1135
Striped Tip
P. O. J. 36
P. O. J. 2878
Natal Uba
Badila
Lahaina

Immediately after planting, the tubs were thoroughly irrigated and covered with a double thickness of wax-paper, which was allowed to remain for three days. Germination was excellent in all tubs.

Fig. 1

Fig. 2

Mahihi Soil
Steam
Sterilized

Fig. 3

Mahihi Soil
Steam
Sterilized
23

Fig. 4

The tubs were planted on March 18, 1931, and beyond being given sufficient irrigation no fertilizer treatment of any kind was used. The plants were harvested from May 26 to June 8 or when they were approximately 75 days old.

In Table I are given the dry weights of the tops and roots of the various varieties.

TABLE I

Showing Dry Weights, in Grams, of Tops and Roots

	Badila		Yellow Caledonia		P.O.J. 2878	
	Tops	Roots	Tops	Roots	Tops	Roots
Unsterilized	157.0	78.5—	135.1	143.9+	132.3	75.5—
Steam sterilized	361.9	369.2+	288.4	514.9+	259.0	271.7+
Formaldehyde sterilized	426.9	259.3—	358.3	275.7—	213.0	132.7—

	D 1135		Striped Tip		P.O.J. 36	
	Tops	Roots	Tops	Roots	Tops	Roots
Unsterilized	106.4	110.7+	91.9	110.8+	83.8	74.9—
Steam sterilized	242.3	247.5+	225.1	163.8—	270.5	320.2+
Formaldehyde sterilized	315.7	199.5—	196.0	244.2+	297.5	333.6+

	H 109		Natal Uba		Lahaina	
	Tops	Roots	Tops	Roots	Tops	Roots
Unsterilized	83.0	45.3—	78.2	101.1+	69.4	45.7—
Steam sterilized	197.0	135.7—	235.9	285.8+	99.8	88.0—
Formaldehyde sterilized	128.4	122.6—	76.2	121.7+	79.7	59.0—

From a study of the above table it can be seen that in every case the sterilized soils showed a greater top and root growth than any unsterilized soil. The top growth of Natal Uba on the formaldehyde sterilized soil shows a slightly depressed weight when compared with that of the unsterilized soil, and the root weight is in favor of the formaldehyde sterilized soil. It is difficult to assign any reason for the lack of top growth.

Figs. 1, 2, 3 and 4 show the growth made by some of the varieties under the different soil treatments.

Through the kindness of C. W. Carpenter, of the pathology department, and R. H. Van Zwaluwenburg, of the entomology department, a study of the root systems was made. The discussion of their findings is given below:

Herewith is submitted a report on an examination of the roots of 27 samples of cane from an experiment conducted by J. N. P. Webster. These 27 samples consisted of 9 varieties in three series as follows.

A Check Makiki soil
B Steam sterilized Makiki soil
C Formaldehyde treated Makiki soil

The varieties of cane were as follows:

D 1135
P. O. J. 2878
Yellow Caledonia
P. O. J. 36
H 109
Lahaina
Badila
Natal Uba
Striped Tip

The top growth of the canes in the treated soils was in general so superior to that of the plants in the natural Makiki soil that it seemed worth while to know whether or not the observed improvement was due to repression of parasitic organisms, and with that in mind the roots were examined.

The root systems of all plants were carefully washed. The following general observations were made:

1. The root growth of the plants in the steam sterilized soil was in most cases superior to, and in all cases at least equal to, that obtained in formaldehyde treated soil.

2. The root systems in the treated soils were in all cases far superior to those in the natural soil. By superior is meant of greater bulk and with a very conspicuous increase of fine rootlets, particularly in the upper 6 inches of soil. (A single exception was the Natal Uba in soil treated with formaldehyde; here depression resulted.)

3. The roots in the treated soils were conspicuously lighter in color than those in the checks.

4. The roots of all three series showed conspicuous injury due to contact with the container.

5. *Heterodera radicicola* and *Tylenchus similis* were identified in all pots of the check series. In every case, however, damage by these nematodes was so slight that it was impossible for us to believe that the marked reduction in root and top growth shown throughout the check series was due to these factors. No evidence of rootlets having been destroyed by nematodes was seen in the check series. In only two cases of treated pots, one steam sterilized, the other formaldehyde treated, were traces of Heterodera found. No Tylenchus was found in roots of treated pots.

6. No evidence of Pythium root rot was observed in the series in treated soils. In the natural soil an occasional softened root was found, but in no case was the fungus Pythium definitely observed. Such roots as were softened appeared to have succumbed as a result of stagnation in the water in depressions at the bottom of the pots.

The striking difference between the roots of treated and check pots was the comparative lack of fine rootlets in the latter. There was no evidence that this lack of fine roots was due to the destruction by parasitic organisms of rootlets already formed. On the contrary such rootlets apparently had never been developed in corresponding abundance in the check plants.

It is our presumption therefore that the essential factors controlling the abundant production of secondary rootlets are physical and nutritional in nature. Where ample nutrients in an improved physical environment were available, a close mat of fine roots developed.

We suggest that if this project is to be followed, a series of soils be included wherein a superabundance of nutrients is present in both sterilized and unsterilized units, to eliminate the possible lack of nutrient factors. Fine screened soil might be used to make the physical condition of steamed and check soil more nearly comparable. Inoculation of a series of steamed soils by the introduction of small amounts of natural soil might throw additional light on the biological-nutritional phases of the problem.

Experiment No. 2

The above showing of the response of the plants to soil sterilization led to the idea of attempting to duplicate the response by the use of high phosphate fertilization, a complete fertilizer mixture and by the use of chloropicrin.

Accordingly, sufficient soil was obtained from Field 3 at Makiki, which was screened and then thoroughly composited. One-half was steam sterilized under pressure for two and one-half hours while the other half was used unsterilized.

It was decided to use the variety D 1135 in this experiment, and to use two tubs for each treatment. The tubs were the same as those used in the previous experiment.

The following were the treatments used in the sterilized and unsterilized soils:

1. Sterilized soil control.
2. " " + 1000 lbs. P_2O_5 per acre.
3. " " + 1500 lbs. P_2O_5 per acre.
4. " " + 100 lbs. N, 500 lbs. P_2O_5, 500 lbs. K_2O per acre.
5. " " + chloropicrin, 75 lbs. per acre.
6. " " + pythium.
7. " " + 2 lbs. unsterilized soil*.
8. Unsterilized soil control.
9. " " + 1000 lbs. P_2O_5 per acre.
10. " " + 1500 lbs. P_2O_5 per acre.
11. " " + 100 lbs. N, 500 lbs. P_2O_5, 500 lbs. K_2O per acre.
12. " " + chloropicrin, 75 lbs. per acre.
13. " " + pythium.

The fertilizers were thoroughly incorporated in the soil before it was placed in the tubs.

In the case of the chloropicrin, soil to a depth of about three inches was first placed in the tubs and then the required amount of chloropicrin was poured on this layer and quickly covered with the amount of soil required to fill the tubs. The tubs were tightly covered with paper and allowed to remain for 4 days.

On July 21, 1931, seed of D 1135 was obtained from Waipio, given the hot water treatment and three seedpieces were planted to every tub. The tubs were then irrigated, covered with paper and left for 3 days before the paper was removed. At this time pure cultures of pythium were added to the designated tubs of the series by thoroughly mixing the cultures in the surface one inch of soil.

Germination and growth of the plants was satisfactory and it was noted that the plants in the sterilized soil series made much better growth than the plants in the unsterilized soil series.

On October 30, the plants in all tubs were photographed, harvested, and the root masses separated from the soil.

Figs. 5, 7, 8, 9 and 10 show the top growth of some of the plants of this series, while Figs. 6 and 11 show the root masses of two groups. In the latter, the mass of very fine fibrous roots can be seen. These were characteristic of the sterilized series in every case.

* This unsterilized soil was obtained from several very poor areas in the upper Ewa corner of Field 8, Makiki.

Fig. 5

Fig. 6

Fig. 7

Fig. 8

Fig. 9

Fig. 10

Fig. 11

Fig. 12

The following table shows the dry weights of the tops and roots of the series.

TABLE II

Treatments	Sterilized Soil		Unsterilized Soil	
	Tops	Roots	Tops	Roots
Check	360.1	140.2	....	....
Unsterilized soil added (2 lbs.)	385.6	134.2	115.6	69.9
1000 lbs. P_2O_5	326.3	130.5	89.6	60.8
1500 lbs. P_2O_5	291.2	132.9	95.8	58.1
100 lbs. N, 500 lbs. P_2O_5, 500 lbs. K_2O	419.6	111.5	160.5	89.8
Pythium	405.1	111.0	86.4	49.1
Chloropicrin 75 lbs. per acre	380.1	145.0	229.6	102.3

A first glance at the above table shows the remarkable gain of the top and root weight of the sterilized soil series over the unsterilized series.

The greater weight of tops and roots of the sterilized soils is in accord with that found in Experiment 1.

The response to chloropicrin in the unsterilized soil is considerable and is probably due to its sterilizing effect upon the soil.

A study of the root systems in the sterilized and unsterilized soils was made by Mr. Van Zwaluwenburg and he comments briefly as follows:

October 30, 1931. Examined today material from two tubs of J. N. P. Webster's experiment, as follows: (1) unsterilized Makiki soil, (2) steam sterilized Makiki soil. Both were supporting plant D 1135 cane, 101 days old.

Examination of roots:

Sterilized soil No nematodes found within the roots.

Unsterilized soil—Colonies of *Tylenchus similis* were found within the roots. Lesions were few on the entire root mass, and not conspicuous.

Examination of soil:

Sterilized—Hoplolaimus sp. (nematode).
One species of amoeboid protozoan.

Unsterilized—Dorylaimus sp. (nematode).
At least 3 species of protozoans:
Paramoecium
Another ciliated protozoan
Amoeboid protozoan

In the *Monthly Letter* for October, 1931, the following resumé was made of the work at Rothamsted in regard to the study of plant growth in sterilized and unsterilized soils:

It has been pointed out upon different occasions that roots grown in sterilized soils are more finely divided and the mass is much greater than those grown in unsterilized soils. In an experiment recently completed by J. N. P. Webster, wherein D 1135 was grown in sterilized vs. unsterilized soils, the various root systems were studied by D. M. Weller in order to determine if the fine roots, that are present in the sterilized soil, actually start in the unsterilized soil and if the absence of these fine roots in the latter are due to parasitic organisms.

A histological study of these roots is in progress and Mr. Weller comments as follows:

"So far certain apparent differences are seen. Immediately outside of the endodermis of the roots in unsterilized soil appears a layer of cells of very much thickened cell walls

and dead protoplasts. This same layer of cells in plants grown in sterilized soil appears to be much less lignified and has fewer dead protoplasts, as though the life of these cells had been prolonged. No doubt this would 'influence absorption.''

As a matter of general interest it seems desirable to present a summary of the research work conducted on this subject by investigators in England. Mr. Carpenter has reviewed some of the literature and offers the following comments:

''This subject was exhaustively studied at Rothamsted Experimental Station under the leadership of Dr. E. J. Russell, during the period 1907-1924. Valuable contributions have been made by Hiltner and Stormer, and by Greig Smith. No attempt has been made to cite or list the abundant correlative literature of Germany, France and America.

''A few of the more significant statements made in the literature, in summarizing extensive research projects, are quoted, as follows:

E. J. Russell and H. B. Hutchinson: The Effect of Partial Sterilization of Soil on the Production of Plant Food, *Journal of Agricultural Science,* Vol. III, 1909, p. 120:

1. The increased productiveness of partially sterilized soils is due to an increase in the amount of ammonia present.

2. The excess of ammonia is the result of increased decomposition of soil substance by bacteria.

3. Hiltner and Stormer's discovery that the bacteria increase rapidly after partial sterilization, and finally become much more numerous than in the original, untreated soil, is confirmed. The increase in number proceeds *pari passu* with the increase in ammonia.

6. Chemical hypothesis having been found unsatisfactory, the factor is shown to be biological. Large organisms (protozoa) were found in untreated, but not in the partially sterilized soils, at least two of which are known to destroy bacteria.

Francis Darbishire and Edward J. Russell: Oxidation in Soils and Its Relation to Productiveness, *Ibid.*, Vol. II, 1907, pp. 325-326:

1. Partial sterilization of soil either by heating to 100° C. or by treatment with volatile antiseptics, which are subsequently removed, leads to a marked increase in the amount of oxygen absorbed by the micro-organisms of the soil.

2. The yield of non-leguminous crops is distinctly larger on partially sterilized than on unsterilized soil. Leguminous crops, however, show no increase.

3. Analysis shows that partial sterilization causes an increase in the amount of nitrogen, phosphoric acid and potash taken up by the crop, and in the percentage of nitrogen and phosphoric acid in the dry matter. . . .

4. The increased availability of the plant food appears to be connected with the modification of the bacteria flora brought about by partial sterilization. When the soil is heated, however, chemical decomposition also takes place.''

The statement is made elsewhere by Dr. Russell that no increase in growth follows partial sterilization of soils amply supplied with ammonia and nitrates.

In the following article by E. J. Russell it is pointed out that in sterilization of the soil the protozoan life is destroyed. Certain protozoa are known to live entirely upon bacteria and in this way the numbers of bacteria are kept in check. Bacteria, because they change into a spore form, are much more resistant to heat than protozoa. Therefore, after sterilization there is an increase in the bacterial flora which is probably responsible for the greater plant growth.

It is interesting to note, in this respect, that in his examination of samples of soil from the sterilized and unsterilized material Mr. Van Zwaluwenburg found only one protozoan species in the sterilized soil whereas in the unsterilized soil he found three forms.

ORGANISMS NOT DIRECTLY AFFECTING PLANT GROWTH BUT ACTING ON THOSE THAT DO.—Investigation on the Partial Sterilization of the Soil.—(From *Soil Conditions and Plant Growth*—By Edward J. Russell, pp. 169-177—Third Edition.)

The earliest observations that soil is altered by an apparently inert antiseptic arose out of attempts to kill insect pests in the soil by means of carbon disulphide. This substance, which for fifty years has been known as an insecticide, was used in 1877 by Oberlin, an Alsatian vine-grower, to kill phylloxera, and by Girard in 1887 to clear a piece of sugar-beet ground badly infested with nematodes. In both cases the subsequent crops showed that the productiveness of the soil had been increased by the treatment.

The first piece of scientific work came from A. Koch, in 1899, who, working with varying quantities of carbon disulphide, concluded that it stimulates the plant root to increased growth. Four years later Hiltner and Stormer showed that the bacterial flora of the soil undergoes a change. The immediate effect of the antiseptic was to decrease by about 75 per cent the number of organisms capable of developing on gelatin plates; then as soon as the antiseptic had evaporated, the numbers rose far higher than before, and there was also some change in the type of flora. It was argued that the increased numbers of bacteria must result in an increased food supply for the plant, and it was claimed that the new type of flora was actually better than the old, in that denitrifying organisms were killed, nitrogen-fixing organisms increased, and nitrification only suspended during a period when nitrates were not wanted and might undergo loss by drainage. In a later publication Hiltner shows that other volatile or easily decomposable antiseptics produce the same effect. The important part of this work is unquestionably the discovery that the organisms in the treated soils ultimately outnumber those in the original soil. The hypothesis that the new type of flora is actually more efficient than the old rests on less trustworthy evidence, and has indeed been modified in some of its details by Hiltner himself.

The effect of heat on the productiveness of the soil was first noticed by the early bacteriologists. It had been assumed that heat simply sterilized the soil and produced no other change, until Frank in 1888 showed that it increased the soluble mineral and organic matter and also the productiveness. Later work by Pfeiffer and Franke and by Krüger and Schneidewind showed that plants actually take more food from a heated than from an unheated soil. Heat undoubtedly causes decomposition of some of the soil constituents quite apart from its effect on the soil flora; it also produces physical effects.

The writer's investigation on this subject began in the first instance as the result of an accident. In virtue of its large population of micro-organisms soil absorbs a considerable quantity of oxygen, and evolves a corresponding amount of carbon dioxide. An experiment had been arranged to demonstrate the well-known fact that soil heated to 130° C., and therefore completely devoid of micro-organisms, lost much of its power of absorbing oxygen. By an accident the autoclave was not available; the soil was therefore only heated in the steam oven, and it gave the remarkable result that its power of absorbing oxygen instead of falling, as was expected, considerably increased. Now the steam did not kill all the organisms, but spared those capable of forming spores; i.e., sterilization was only partial. Partial sterilization by means of volatile antiseptics gave the same result. The conclusion was drawn that partial sterilization increased the bacterial activity, and consequently the amount of decomposition. The increased quantity of plant food thus formed is shown by the amounts taken up by the plant.

Further investigations by Russell and Hutchinson led to the following conclusions:

(1) Partial sterilization of soil, i.e., heating to a temperature of 60° C. or more, or treatment for a short time with vapors of antiseptics such as toluene, causes first a fall then a rise in bacterial numbers. The rise sets in soon after the antiseptic has been removed and the soil conditions are once more favorable for bacterial development; it goes on till the numbers considerably exceed those present in the original soil.

(2) Simultaneously there is a marked increase in the rate of accumulation of ammonia. This sets in as soon as the bacterial numbers begin to rise, and the connection between the

two quantities is normally so close as to indicate a causal relationship; the increased ammonia production is, therefore, attributed to the increased numbers of bacteria. There is no disappearance of nitrate; the ammonia is formed from organic nitrogen compounds.

(3) The increase in bacterial numbers is the result of improvement in the soil as a medium for bacterial growth and not an improvement in the bacterial flora. Indeed the new flora per se is less able to attain high numbers than the old. This is shown by the fact that the old flora when reintroduced into partially sterilized soil attains higher numbers and effects more decomposition than the new flora. Partially sterilized soil plus 0.5 per cent of untreated soil soon contains higher bacterial numbers per gram and accumulates ammonia at a faster rate than partially sterilized soil alone.

(4) The improvement in the soil brought about by partial sterilization is permanent, the high bacterial numbers being kept up even for 200 days or more. The improvement, therefore, did not consist in the removal of the products of bacterial activity, because there is much more activity in partially sterilized soil than in untreated soil. Further evidence is afforded by the fact that a second treatment of the soil some months after the first produces little or no effect.

It is evident from (3) and (4) that the factor limiting bacterial numbers in ordinary soils is not bacterial, nor is it any product of bacterial activity, nor does it arise spontaneously in soils.

(5) But if some of the untreated soil is introduced into partially sterilized soil, the bacterial numbers, after the initial rise (see (3)), begin to fall. The effect is rather variable, but is usually most marked in moist soils that have been well supplied with organic manures, e.g., in dunged soils, greenhouse soils, sewage farm soils, etc. Thus the limiting factor can be reintroduced from untreated soils.

(6) Evidence of the action of the limiting factor in untreated soils is obtained by studying the effect of temperature on bacterial numbers. Untreated soils were maintained at 10°, 20°, 30°, C., etc., in a well-moistened, aerated condition, and periodical counts were made of the numbers of bacteria per gram. Rise in temperature rarely caused any increase in bacterial numbers; sometimes it had no action, often it caused a fall. But after the soil was partially sterilized the bacterial numbers showed the normal increase with increasing temperatures.

EFFECT OF TEMPERATURE OF STORAGE ON BACTERIAL NUMBERS IN SOILS, MILLIONS PER GRAM

Temperature of Storage ° C.	Untreated Soil				Soil Treated with Toluene			
	At start	After 13 days	After 25 days	After 70 days	At start	After 13 days	After 25 days	After 70 days
5°-12°	65	63	41	32	8.5	73	101	137
20°	65	41	22	23	8.5	187	128	182
30°	65	27	50	16	8.5	197	145	51
40°	65	14	9	33	8.5	148	52	100

Similar results were obtained by varying the amount of moisture but keeping the temperature constant (20° C.). The bacterial numbers in untreated soil behaved erratically and tended rather to fall than to rise when the conditions were made more favorable to trophic life; on the other hand, in partially sterilized soil, the bacterial numbers steadily increased with increasing moisture content. Again, when untreated soils are stored in the laboratory or glass-house under varying conditions of temperature and of moisture content the bacterial numbers fluctuate erratically; when partially sterilized soils are thus stored the fluctuations are regular.

(7) When the curves obtained in (6) are examined it becomes evident that the limiting factor in the untreated soils is not the lack of anything but the presence of something active.

(8) This factor, as already shown, is put out of action by antiseptics and by heating the soil to 60° C., and once out of action it does not reappear. Less drastic methods of treating the soil put it out for a time, but not permanently; e.g., heating to 50°, rapid

drying at 35°, treatment with organic vapors less toxic than toluene (e.g., hexane), incomplete treatment with toluene. In all these cases the rise induced in the bacterial numbers per gram is less in amount than after toluene treatment and is not permanent; the factor sets up again. As a general rule, if the nitrifying organisms are killed the limiting factor is also extinguished; if they are only temporarily suppressed the factor also is only put out for a time.

(9) The properties of the limiting factor are:

(a) It is active and not a lack of something (see (7)).

(b) It is not bacterial (see (3) and (4)).

(c) It is extinguished by heat or poisons, and does not reappear if the treatment has sufficed to kill sensitive and non-spore-forming organisms; it may appear, however, if the treatment has not been sufficient to do this.

(d) It can be reintroduced into soils from which it has been permanently extinguished by the addition of a little untreated soil.

(e) It develops more slowly than bacteria, and for some time may show little or no effect, then it causes a marked reduction in the numbers of bacteria, and its final effect is out of all proportion to the amount introduced.

(f) It is favored by conditions favorable to trophic life in soil, and finally becomes so active that the bacteria become unduly depressed. This is one of the conditions obtaining in glass-house "sick" soils.

It is difficult to see what agent other than a living organism can fulfil these conditions. Search was, therefore, made for larger organisms capable of destroying bacteria, and considerable numbers of protozoa were found. The ciliates and amoebae are killed by partial sterilization. Whenever they are killed the detrimental factor is found to be put out of action, the bacterial numbers rise and maintain a high level. Whenever the detrimental factor is not put out of action the protozoa are not killed. To these rules we have found no exception.

NUMBERS OF BACTERIA AND AMMONIA PRODUCTION IN PARTIALLY STERILIZED SOILS

Soil Treatment	Number of Organisms per Gram of Dry Soil, in Millions, Gelatin Plate Cultures					Protozoa Found	Ammonia and Nitrate produced after 68 days
	At beginning	After 7 days	After 21 days	After 68 days	After 142 days		
Untreated	11	10	12	11	4	C. A. M.	14
Heated to 40°...	7	9	10	8	3	C. A. M.	15
56°...	2	14	16	38	48	M	60
70°...	2	17	11	24	27	M	38
100°...	0.01	17	22	10	10	...	44

C = ciliates. A = amoebae. M = Monads.

Further, intermediate effects are obtained when a series of organic liquids of varying degrees of toxicity is used in quantities gradually increasing from small ineffective up to completely effective doses. The detrimental factor is not completely suppressed but sets up again after a time, so that the rise in bacterial numbers is not sustained. But the parallelism with ciliates and amoebae is still preserved; they are completely killed when the detrimental factor is completely put out of action; they are not completely killed, but only suppressed to a greater or less degree, when the detrimental factor is only partly put out of action.

Now the parallelism between the properties of the detrimental factor and the protozoa is not proof that the protozoa constitute the limiting factor, but it affords sufficient presumptive evidence to justify further examination. The obvious test of adding cultures of protozoa to partially sterilized soil was made, but no depression in bacterial numbers was obtained, instead there was sometimes a rise. But in view of the history of investigations on malaria and other protozoan diseases no great significance was attached to this early failure.

At this stage the investigation was divided into two parts:

(1) The study of the soil protozoa.

(2) The effects of the limiting factor on the biochemical processes on the soil.

No attempt had ever been made in any of the above experiments to identify the protozoa or even to ascertain whether any particular form existed in the soil in the trophic state or as cysts. The variety of forms was considerable, and it soon became evident that a definite protozoological survey of the soil was required.

This was accordingly put in hand. In order to give the survey as permanent a value as possible the investigations were not confined to the narrow issue whether soil protozoa do or do not interfere with soil bacteria, but they were put on the broader and safer lines of ascertaining whether a trophic protozoan fauna normally occurs in soil, and, if so, how the protozoa live, and what is their relation to other soil inhabitants.

The first experiments were made by Goodey mainly with ciliates and indicated that these protozoa were present only as cysts. Subsequent investigations, however, by Martin and Lewin have established the following conclusions:

(1) A protozoan fauna in a trophic state normally occurs in soils.

(2) The trophic fauna found in the soil differs from that developing when soil is inoculated into hay infusions; the forms which appear to predominate in the soil do not predominate in the hay infusions, and vice versa the forms predominating in the hay infusions do not necessarily figure largely in the soil.

(3) The trophic fauna is most readily demonstrated, and is therefore presumably most numerous, in moist soils well supplied with organic manures, e.g., in dunged soils, greenhouse soils, sewage soils and especially glass-house "sick" soils.

Finally, the latest experiments by Goodey have shown that when this trophic fauna is introduced into partially sterilized soils the bacterial numbers are brought down. The earliest attempts to carry out this experiment failed as already stated, only one successful experiment by Cunningham being on record. It was not till Goodey discovered the conditions for successful inoculation that it could be carried out. Goodey found that mass cultures of protozoa failed when introduced direct from a culture medium into partially sterilized soils, but succeeded when introduced through the medium of some untreated soil. In these circumstances the protozoa lived, and the numbers of bacteria were reduced. The protozoa used in these investigations were amoebae of the limax type, these being the forms common in the soil.

Thus it was proved that these protozoa lead an active life in the soil, and that one result of their activity is to keep down the numbers of bacteria.

The following summary of the work done by Waksman and Starkey at the New Jersey Agricultural Experiment Station in the article entitled "Partial Sterilization of Soil, Microbiological Activities and Soil Fertility," *Soil Science*, Vol. XVI, 1923, pp. 137-156, 247-268, 343-356, is of interest:

From page 355:

1. Partial sterilization of soil brings about a chemical change in the organic matter of the soil, making it more available as a source of energy for micro-organisms. This is indicated by (a) the ammonia formation (even if only a small amount) in the process of sterilizing the soil by heat or disinfectants; (b) by the fact that the curve of CO_2-evolution in partially sterilized soil is similar to that obtained when a small amount of undecomposed organic matter is added to unsterilized soil; (c) by the fact that soils rich in organic matter allow a greater accumulation of ammonia and nitrates, as a result of partial sterilization, than soils poor in organic matter, independent of the flora and fauna; (d) partially sterilized soil with a much greater bacterial flora is no more efficient in decomposing nitrogenous and non-nitrogenous organic substances added to it.

2. A large proportion of the soil fungi are killed as a result of partial sterilization. This dead material with the bodies of destroyed protozoa and other micro-organisms still further increases the amount of energy made available in the soil.

3. The rapid increase in the numbers of micro-organisms in the soil is at the expense of the organic matter made available. This is further confirmed by the fact that the course of development of fungi results in a curve somewhat similar to that given by the bacteria, although the rise in the curve may take place at a later date. The numbers of fungi, however, may not indicate the period of maximum activity which may have been passed already. Large numbers of fungi, shown by the plate method, may be due to abundance of spores. Where active growth of fungi takes place, due to available nutrients, spore formation may be greatly delayed. The vegetative mycelium, however extensive, may show much smaller numbers than when spore formation occurs.

4. The carbon and nitrogen are present in the soil in a certain proportion, depending upon the physical and chemical condition of the soil; when the carbon compounds are decomposed as sources of energy by the bacteria and actinomycetes some of the nitrogen is left as a waste product. The carbon-nitrogen content of the soil and of the bodies of the bacteria, actinomycetes and fungi combined with the economic utilization of the carbon by these three groups of organisms, explain why the development of the first two groups of organisms will bring about the liberation of nitrogen from the soil organic matter to a greater extent than the development of the fungi.

5. The actual amount of ammonia formed in partially sterilized soil is determined not by the numbers of bacteria and fungi developing in the soil, but by the abundance of organic matter. The course of development of numbers of bacteria in the soil seems to be influenced by the course of development of the fungi. The course of development of actinomycetes depends upon the method used in bringing about the partial sterilization of the soil as well as by the organic matter content of the soil.

6. The protozoa are suppressed in partially sterilized soil, but become active again long before the bacterial numbers drop down very markedly.

7. The more rapid the rise in bacterial numbers and the greater the maximum, the sooner will the fall set in. This is exactly true of the numbers of fungi. These phenomena are results of the amount of available plant food in the soil.

8. The phenomena observed as a result of partial sterilization of soil, namely the rise of bacterial numbers and ammonia accumulation are explained by (a) the change in the physical condition of the soil, especially the soil colloids, (b) the change in chemical condition, especially modification of soil organic matter, making it more readily available; (c) the destruction of a large number of soil micro-organisms, especially the fungi and protozoa, making their bodies available as sources of energy for the surviving micro-organisms; (d) the change in balance of the microbiological flora of the soil (all of these favor greatly the development of the bacteria); and (e) the fact that bacteria use organic nitrogenous substances (as well as other carbon compounds) very uneconomically as sources of energy and liberate a great deal of ammonia as well as phosphates and other minerals stored away in the soil organic matter as waste products.

9. These results apply to normal soils. It is possible that under certain conditions other phenomena become controlling factors. We need only mention soils infested with fungi causing plant diseases or sewage farming and greenhouse soils, where protozoa may become controlling factors.

Acknowledgment

The writer wishes to thank A. J. Mangelsdorf, C. W. Carpenter, Douglas A. Cooke and D. M. Weller for their cooperation in the above study.

Sugar Prices

96° CENTRIFUGALS FOR THE PERIOD
MARCH 16, 1932, TO JUNE 16, 1932

Date	Per Pound	Per Ton	Remarks
Mar. 16, 1932	2.765¢	$55.30	Porto Ricos, 2.78, 2.77, 2.76; Philippines, 2.76; Cubas, 2.76, 2.75.
" 17	2.75	55.00	Porto Ricos.
" 18	2.71	54.20	Porto Ricos, 2.72, 2.71; Philippines, 2.72, 2.71, 2.70.
" 21	2.755	55.10	Philippines, 2.76, 2.75.
" 22	2.745	54.90	Cubas, 2.75; Philippines, 2.74.
" 24	2.735	54.70	Philippines, 2.74, 2.73; Cubas, 2.73; Porto Ricos, 2.73.
" 28	2.725	54.50	Philippines, 2.73; Porto Ricos, 2.72.
" 29	2.695	53.90	Porto Ricos, 2.70, 2.69; Philippines, 2.70.
" 30	2.69	53.80	Philippines.
" 31	2.685	53.70	Philippines, 2.69, 2.68.
April 1	2.675	53.50	Philippines, 2.69, 2.66; Porto Ricos, 2.69.
" 5	2.65	53.00	Porto Ricos, 2.66, 2.65, 2.64; Philippines, 2.66.
" 6	2.605	52.10	Porto Ricos, 2.60; Philippines, 2.61.
" 7	2.60	52.00	Philippines, Porto Ricos.
" 8	2.66	53.20	Philippines.
" 13	2.605	52.10	Philippines, 2.60; Porto Ricos, 2.61.
" 14	2.64	52.80	Porto Ricos, 2.63, 2.65.
" 15	2.65	53.00	Cubas, Philippines, 2.65.
" 18	2.63	52.60	Porto Ricos, Philippines.
" 19	2.61	52.20	Porto Ricos.
" 22	2.63	52.60	Porto Ricos, Philippines.
" 23	2.65	53.00	Porto Ricos.
" 27	2.64	52.80	Philippines, 2.63; Porto Ricos, 2.65.
" 28	2.62	52.40	Porto Ricos, Philippines.
May 2	2.60	52.00	Philippines, Porto Ricos.
" 3	2.605	52.10	Philippines, 2.61; Porto Ricos, 2.61, 2.60.
" 4	2.60	52.00	Porto Ricos, Philippines.
" 5	2.58	51.60	Porto Ricos, Philippines.
" 7	2.58	51.60	Philippines.
" 10	2.63	52.60	Porto Ricos, 2.62, 2.63, 2.64; Philippines, 2.62; Cubas, 2.62.
" 11	2.60	52.00	Cubas.
" 13	2.59	51.80	Porto Ricos.
" 14	2.58	51.60	Porto Ricos.
" 16	2.585	51.70	Porto Ricos, 2.59; Philippines, 2.58.
" 17	2.58	51.60	Porto Ricos.
" 19	2.60	52.00	Philippines, Porto Ricos.
" 20	2.58	51.60	Philippines.
" 27	2.60	52.00	Porto Ricos, Philippines.
" 31	2.57	51.40	Philippines.
June 3	2.60	52.00	Cubas, Philippines.
" 6	2.62	52.40	Porto Ricos, Philippines.
" 8	2.62	52.40	Porto Ricos.
" 9	2.65	53.00	Philippines.
" 10	2.65	53.00	Philippines.
" 13	2.71	54.20	Philippines, 2.70; Porto Ricos, 2.70, 2.72; St. Croix, 2.70.
" 14	2.75	55.00	Porto Ricos, Philippines.
" 16	2.795	55.90	Porto Ricos, 2.79, 2.80; Philippines, 2.80.